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A BRIEF SURVEY OF THE TECTONICS OF INDOCHINA[1]

by

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This article describes the tectonic regionalization of Indochina in the Mesozoic stage of its eologic history, which terminated the geosynclinal development of this region. The ages of the eosynclinal cycles are determined by the times in which their folding came to an end.

Two categories of geological structures are distinguished in this territory — ancient massifs nd geosynclinal zones. The author concludes that there are earlier Mesozoic tectonic structures ı Indochina.

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The territories of the peninsula of Indochina nd the areas of Tonkin, Upper Laos and Yunnan ave been very little studied from the geologic tandpoint. This is due partly to the fact that ıe few tectonic schemes of this territory to a onsiderable degree merely reflect the theoretcal views of their authors.

One of the greatest authorities on the geology f Southeast Asia, J. Fromaget, believes that ıe geologic development of Indochina was deterıined by forces of compression and extension, rising periodically during the horizontal dislacements of the continents Gondwana and urasia. The areas of Indochina, located beween these continents, were repeatedly fracured, then again consolidated, and folded ccording to the direction of these displaceıents. In attributing primary importance to angential tectonic forces, J. Fromaget and ther French geologists believe that Indochina, articularly the northern part, is characterized y numerous tectonic allochthonous thrust heets, although in many cases the existence f such structures has not been proved beyond ny possible doubt.

Among Soviet investigators, the geologic tructure of Indochina has been briefly examined y P.N. Kropotkin [5]. In his tectonic map of ndochina and adjoining territories, on a scale f 1:20,000,000, P.N. Kropotkin distinguishes n Indochinese central massif, bordered on the vest by a zone of Hercynian and, on the east, f Mesozoic folding. The latter, according to '. N. Kropotkin, is analogous to the Mesozoic tructures on the Malaccan Peninsula.

The tectonic regionalization of Indochina suggested by the present writer differs strikingly from those mentioned above. Using the available material in the literature (primarily papers by French geologists), this author has attempted to construct a diagrammatic tectonic map of Indochina. This map is based on a subdivision of the series of sedimentary deposits into structural stages, corresponding to the natural stages in the geologic development of this territory. The necessary deviations from this principle are due to the fact that certain formations, apparently of Precambrian age, have still been very little studied. These can be subdivided only into post-orogenic formations, exposed in the cores of anticlines and in horsts within geosynclinal zones, and prefolding formations, which crop out in the uplifted parts of stable massifs. In both cases they form the metamorphic basement of the geosynclines or massifs. The ages of the geosynclinal cycles are determined by the time of the folding which completed their development. In his tectonic regionalization of Indochina the present writer has unfortunately not been able to make full use of the morphological criteria of structures, since almost no such descriptions exist in the literature.

The general structural plan of Indochina is determined by rigid massifs and the geosynclinal zones that separate them. The greatest of these are the Indochinese, the Northern Tonkin and the Pursat massifs; the major geosynclinal zones are the Amnam, the Western Cambodian and the Tonkin (see map).[2]

[1]Kratkiy ocherk tektoniki Indokitaya.

[2]In the case of the major structures, this writer has attempted, as far as possible, to retain the names that already exist in the literature. The Indo-

The Indochinese massif occupies the lowland areas of Siam, Cambodia, Southern Laos and the plains of Darlak and Kontum, and is surrounded on three sides by mountain ranges of folded structures. This massif is the major block structure of Indochina and determines the tectonics of geosynclines adjoining it.

The uplifted eastern part of the Indochinese massif, known as the Kontum massif, forms the flatlands of Darlak[3] and Kontum. To the north lies the Bak-ma spur [14] — a zone of crystalline formations extending from Tourane to Tshepone and separated from the main part of the massif by a superimposed trough.

The Kontum massif is composed almost entirely of ancient crystalline rocks, which are evidently analogous to the basement rocks of the buried part of the Indochinese massif. The most ancient, which are supposed to be Archean, are widespread here and are represented [4] by formations of calcium-alkaline orthogneisses, amphibolites, paragneisses with biotite, garnet and amphibole. Above this lie Proterozoic (?) formations: mica sillimanite schists, altered carbonates, paraamphibolites and granite-gneisses. On the Pleiku plateau, in the southwestern part of the Kontum flatland, Lower Paleozoic (?) metamorphosed rocks have been observed lying unconformably upon Precambrian (E. Saurin's Bokham series). This is represented by interlayered pyroxene, amphibole and biotite paragneisses, crystallized limestones, pyroxenites and amphibolites. In their composition and stratigraphic position these rocks are comparable to the Caledonian (?) formations of the Southern Annam massif (Balat series), and also to the Cambrian-Silurian (?) of Northern Indochina and Cambodia.

The metamorphic formations of the Kontum massif have been dislocated in a very complex manner. According to E. Saurin [5] and J. Hoffet [21], there is a predominance of submeridional trends and extensive faulted dislocations, evidently produced by the Hercynian and Mesozoic tectogenesis. The faults have served as paths for the intrusion of the granitoids which are grouped in chains north to south.

Within the buried part of the Indochinese massif the rocks of the folded metamorphic basement are not exposed, and the structure of the sedimentary mantle consists of two stages.[4]

The lower structural stage, to judge from several small outcrops, is composed of pre-Middle Carboniferous metamorphic rocks.[5] In a small outcrop (extending for some few tens of kilometers), composed of nearly horizontal bedded micaceous quartzites and shales, south of the village of Melouprey, was found the trilobite Asaphiscus gregarius, which dates these rocks as Cambrian [8]. An exposure of Devonian lyddites, which have clearly not been affected by the Hercynian movements, occurs near the mouth of the Srepok River. Moreover in the zone connecting the downwarped and uplifted (the Kontum massif) parts of the Indochinese massif, Paleozoic sedimentary rocks crop out at the surface. In this fault zone they are considerably dislocated. Here one may observe Middle Devonian sandy limestones containing Eifelian brachiopods, as well as lesser amounts of sandstones and shales. Along the western boundary of the Kontum massif, exposures of these rocks extend for a distance of some 130 km. The thickness of the Devonian deposits has been measured as 2 – 3 m [21]. A continuation of this belt to the south forms outcrops of Devonian rocks along the margin of the Kontum massif, between the valleys of the Nam-Kong and Se-Son Rivers [14]. In the north the Eifelian limestones are overlain, with an erosional gap, by shales of the Middle and Upper Coal Measures with sand-gravel deposits containing fragments of plant remains. This thick continental series, which belongs to the bottom of the upper structural stage, is also dislocated. Judging by the profile drawn by J. Hoffet through the middle reaches of the Sekamane River, these Paleozoic deposits form a monocline dipping toward the east at an angle of 40 – 50° [21].

The upper structural stage of the sedimentary mantle on the Indochinese massif is composed of continental and subcontinental sediments,

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chinese massif appears in the papers by E. Suess as the "Cambodian mass" (E. Suess, Survey of the Earth, Vol. 3, 1908). J. Fromaget and other French geologists [8, 17] call this massif "The Indochinese platform." "The Kontum massif," the uplifted eastern part of the Indochinese massif, has been called by F. Blondel [12] the "Central Indochinese massif" and somewhat later the "Annam massif," and by E. Saurin the "Kontum massif" [25], since the greater part of its territory is occupied by the Kontum plateau. The name "Northern Tonkin massif" has been used by Huan Bo'tsin [9]. In works by J. Fromaget and A.S. Adelung this structure is called the "Upper Shong-Chay arch" ("Shong-Chay" is translated as "Red River"). The Pursat massif takes its name from Pursat, the greater part of which is located in its territory.

[3] The reader is advised to use the physico-geographic map of Indochina to be found in the Atlas Mira (Atlas of the World) [1].

[4] In the downwarped part of the Indochinese massif the map shows only the largest outcrops of the rocks of the lower structural stage.

[5] With the exception of the areas attached to the massif as a result of the Hercynian folding. These will be considered below.

elonging in time to the late middle Carbonif- rous through the Cretaceous inclusive. These ave been distinguished and described by Fromaget as "Indosinian" deposits[6] [8, 17]. he Indosinian deposits are subdivided into iree series, each characterized by its litho- ogic composition, and separated from the others y gaps in sedimentation.

The lower of these series includes rocks ormed from the end of Moscovian times to the arlier half of the Carnian age, corresponding the interval of time between the Hercynian nd Mesozoic folding in the geosynclines. This eries transgressively overlies all the under- ing formations and is represented by greenish nd bluish felspathic sandstones and shales, hich sometimes contain coal. Within it are enses of marine sandstones and limestones ith fusulines and brachiopods, as well as flows f igneous rocks — andesites, dacites and rhyo- tes.

The period in which the middle series of the idosinian sediments was deposited corresponds the time of intensive Upper Triassic folding he later part of the Carnian and earlier part of ie Norian ages) in the geosynclines. These eposits are represented almost wholly by the o-called "lower redbeds": varieties of clays nd sandstones which sometimes contain coal r gypsum. Only in Western Cambodia do the liddle Indosinian series contain clastic gray- ol--ed facies. The middle series is charac- erized by a large number of local gaps in sedi- ientation.

The Upper Indosinian series is composed of haetian, Jurassic and Cretaceous continental eposits and occurs in the eastern half of the wnwarped part of the Indochinese massif, orth of the Dangrek mountain chain. They con- ist of red and white continental sandstones ontaining carbonaceous clay strata and marls; a part they are made up of redbed facies and vaporites.

The total thickness of all three series of idosinian deposits has been estimated variously y different authors; it apparently increases ast of the downwarped part of the Indochinese iassif. In the Korat plateau the average thick- ess of the Indosinian deposits has been meas- red as 1200 m [14].

From the above it follows that the interrup- ions in sedimentation dividing the Indosinian eposits into series were determined by the Jpper Triassic, apparently Rhaetian, tectonic novements, which were intensively manifested in the geosynclines surrounding the massif.

The rocks of the sedimentary mantle on the Indochinese massif, including the Cambrian and Devonian deposits, occur with flat, gentle slopes. It is interesting to note that part of the above-described outcrops of the lower structural stage of the mantle may possibly gravitate toward an enormous hypothetical fault within the body of the massif (the "Se-Kong gulf" – see J. Fromaget, [17]). The direction of this supposed fault is indicated by the trend of the elongated intrusive bodies of rhyolites, granites and basic rocks (see map). Almost nothing is known of the nature of this linearity.

<u>Areas of Hercynian folding of the Indochinese massif.</u> After the tectogenesis at the time of Middle Coal Measures, the Hercynian geosynclinal areas were uplifted and ultimately came to be stable regions attached to the Indochinese massif and surrounded by zones of Mesozoic folding. This writer believes that these areas have been parts of the Indochinese massif since the end of the upper Paleozoic.

One such area is the Southern Annam massif [27]. This vast and complicated uplift occupies the extreme southern part of Southern Vietnam and is separated from the ancient Indochinese massif by superimposed structures — the Cochinchin trough and the Mekong valley. The Precambrian formations within the Southern Annam massif have been only tentatively distinguished; they are not widely distributed, and are represented primarily by acidic "ortho" rocks. They are undonformably overlain by the intensively altered rocks of the Dalat series developed in the central and southern parts of the Southern Annam massif.

According to E. Saurin [26], the composite section through this series contains the following (from bottom to top): 1) muscovite and felspar schists and quartzites; 2) flows of labradorite andesites, grading into amphibolites; 3) biotite and actinolite schists and quartzites; 4) at the top of the series, layers of metamorphosed conglomerates containing pebbles from strata 1 – 3.

The French geologists have tentatively given the age of the Dalat series as Cambrian-Silurian. Here these rocks have been highly crumpled and crushed. The general trend of the series is north-northeast. The metamorphic formations are overlain unconformably by a thick series of shales, sandstones and phthanites. The stratigraphic position of these rocks (between the Dalat series and deposits of the upper Carboniferous-Permian), their lithologic composition, and the occurrence of Lower Coal Measures foraminifera in the uppermost beds, indicate that the age of this series is approximately Devonian — Lower Carboniferous. In

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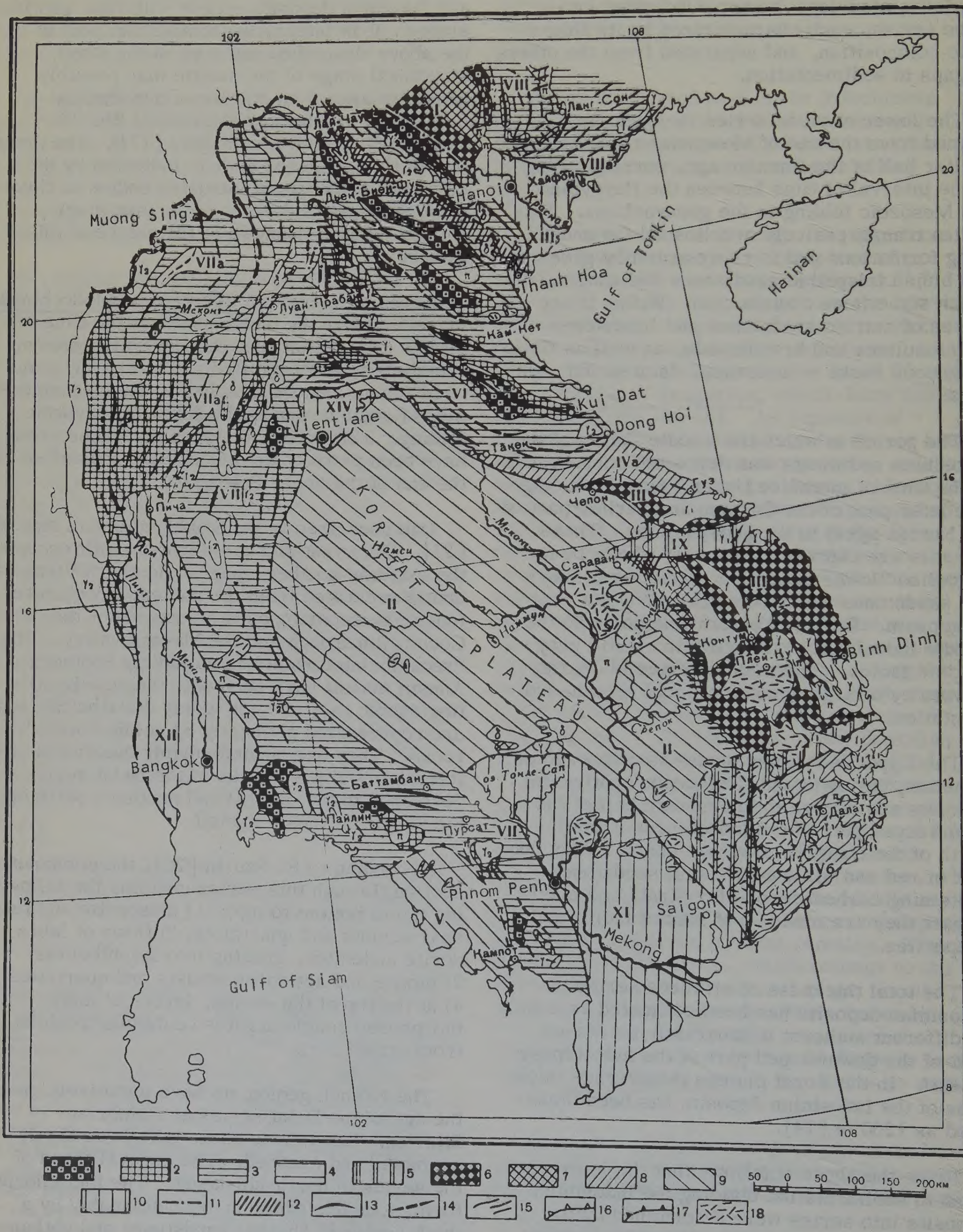
[6] The Indosinian deposits, especially their upper eries, occur not only within the Indochinese massif, ut over a considerably greater territory -- that of he Hercynian and Mesozoic folded structures.



TECTONIC SKETCH MAP OF INDOCHINA

Middle Coal Measures time the rocks described here were altered to hornstones by the numerous intrusions of alkaline granites and crumpled into complex folds trending northeast.

Upon the Middle Paleozoic rocks, after a sharp angular unconformity and a basal stratum of conglomerates, lie the relatively thin sandstone and shale deposits of the Upper Paleozoic. These have been pushed into gentle, undulating folds. The most complete sections through these deposits have been described in the Dzhiring plateau, at the southwestern margin of the Annam massif. Here the marine sedimentation continued for the longest time, so that littoral sand and clay sediments were being deposited until the end of the Permian [25]. The Southern Annam massif was finally uplifted in the Early Triassic. The Mesozoic deposits in its territory are represented by continental and igneous formations.

The other, Tourane-Thakhek, area of Hercynian folding is located between the southern end of the Annamit geosyncline (south of Dong-Hoy) and the northern end of the Kontum massif. Here Devonian rocks form a belt of outcrops extending from the vicinity of Tourane northwestward to Thakhek. In this area the sedimentary formations in the south transgressively overlie the Precambrian of the Kontum massif, and in the north are unconformably covered by the post-Hercynian limestone and shale deposits of the Annamit geosyncline. The section begins with Middle Devonian sandstones, shales and limestones containing brachiopods; above these conformably lie Upper Devonian, primarily sandstone, rocks.

In the Tournaisian age this territory formed a dry land. Visean deposits, beginning with conglomerates, are known only in the area north of Tschepone. On the whole, as compared to the more northern areas of the Hercynian Annamit geosyncline, the Middle Paleozoic facies are here observed to be coarser, and the section is curtailed. The Hercynian movements crumpled the Middle Paleozoic strata of the Tourane-Thakhek areas into folds trending northwest. After the Middle Carboniferous tectogenesis there was no more marine sedimentation in the areas of Tourane and Thakhek.

From what has been said above it will be seen that the Indochinese massif has a complicated and heterogeneous structure. In relation to the Mesozoic geosynclinal folded areas, however, it behaved as a single rigid block. The massif is quite sharply separated from the adjacent geosynclinal zones: these boundaries apparently correspond to large fractures in the depths. Around the periphery of the massif the rocks of the sedimentary mantle are crumpled into undulating folds, in which ruptural dislocations are quite prominent. Within this same peripheral zone the continental Indosinian facies of the lower and middle series are frequently replaced by their marine geosynclinal analogs (at the boundary with the Annamit geosyncline, for example).

The Pursat massif occupies almost the entire territory of the Kardamon Mountains. Part of it probably lies beneath the waters of the Gulf of Siam. The chief evidence for the existence of the Pursat massif is the sharp change in the trend of the folds in the

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Illustration:

Geosynclinal zones (1 - 5): 1 -- metamorphic basement rocks ($PCm + Pz_1?$); 2 -- lower structural stage (Pz_{1+2}); 3-4 -- upper structural stage; substages: 3 -- lower ($C^s - T_1$) and middle ($T_2^1 - T_3$), 4 -- upper ($T_3 - J_1$); 5 -- superimposed troughs ($T - J_1$). Central Massifs (6 - 9): 6 -- metamorphic basement rocks ($PCm - Pz_1?$); 7-8 -- lower structural stage: 7 -- rocks lying conformably on basement and dislocated in fault zones (Pz_{1+2}), 8 -- dislocated rocks (Pz_{1+2}) broken into massifs as a result of Hercynian (C_2) folding; 9 -- upper structural stage ($C^s_2 - Cr$); 10 -- superimposed Quaternary basins. Structures: 11 -- faults; 12 -- zones of brecciation; 13 -- anticlines; 14 -- synclines; 15 -- strikes; 16 -- outlines of Quaternary basins; 17 -- boundaries of central massifs.

Igneous rocks: -- basic and ultrabasic intrusives of all ages; 1 -- Hercynian (C_2) granitoids; 2 -- Mesozoic (primarily T_3) granitoids; -- granitoids of undetermined ages; -- hypabyssal and extrusive formations: andesites, dacites, rhyolites (primarily $Pz_3 - T_1$); 18 -- Cenozoic basalts.

Roman numbers on map:

Central massifs: I -- Northern Tonkin; II -- buried part of Indochinese massif; III -- exposed parts of Indochinese massif (Kontum massif); IV -- areas of Hercynian structures broken into massifs: IVa -- Hue-Takek region, IVb -- Southern Annamese massif; V -- Pursat massif.

Geosynclinal zones: VI -- Annamese, VIa -- zone of major linear structures; VII -- Western Cambodian, VIIa -- Upper Laotian; VIII -- Tonkin, VIIIa -- Mon-Kay region.

Superimposed troughs: IX -- An-Diem; X -- Cochinchin.

Superimposed Quaternary basins: XI -- Mekong; XII -- Menam; XIII -- Hanoi; XIV -- Vientiane.

geosynclinal zone, where they go around the Cardamon Mountains. The entire territory of this supposed massif is covered by undisturbed marine sandstones. This massif is only tentatively distinguished, however, since the information on the geology of these regions is very scanty.

The Northern Tonkin massif lies in Northern Tonkin and in part of the territory of Yunnan (Southern China), between the valleys of the Red River and the Pan'luntszyan River. This massif is ringed on three sides by folded formations, and on the southwest is terminated by a large and very narrow graben.

The Northern Tonkin massif is composed of Precambrian and Paleozoic (pre-Lower Carboniferous rocks, not dated with greater precision). Here the Paleozoic formations are subordinate and occupy primarily the eastern margin of the massif. Its more uplifted western part, where Archean rocks are exposed along the Red River graben, is composed of crystalline schists and gneisses. After an erosional gap these are overlain by formations of the Proterozoic (and, perhaps, in the upper part, of the Paleozoic), represented by mica schists, gneisses, amphibolites, limestones altered to marble, and micaceous quartzites.

The upper part of the section through the Northern Tonkin massif is composed of undivided pre-Lower Carboniferous deposits of very varied lithologic composition (sandy shales, limestones and marbles, micaceous shales, etc.). These correspond to the lower structural stage of the sedimentary mantle over the Indochinese massif. The metamorphic rocks that compose the Northern Tonkin massif have been subjected to very complex dislocations trending predominantly northwest, (verbal communication from A. S. Adelung).

The Mesozoic geosynclinal zones of Indochina include the Annamit, the Western Cambodian ("the Annamit and Western Cambodian curve" according to J. Fromaget – [8, 17]) and the Tonkin geosynclines ("The Tonkin curve" according to Huan Bo-Tsin – [19]). In addition, these geosynclines include isolated large areas characterized by peculiar tectonic structures. For example, in the Annamit geosyncline there is a zone of large linear structures, located in the western part of Tonkin. The northern part of the Western Cambodian geosyncline – the territory of Upper Laos, which underwent great subsidence at the end of the Mesozoic geosynclinal cycle – must be described separately. Another area that subsided during the Mesozoic is the "Mon-Kay syncline", as it is called by the French geologists, located south of the Tonkin geosyncline. The question of whether the Mon-Kay area belongs to the Tonkin geosyncline or should be set apart as an independent structural unit is a controversial one and will not be answered here.

The Annamit geosyncline surrounds the Indochinese massif on the northeast. Let us first consider the most thoroughly studied section through the sedimentary deposits of the Annamit geosyncline proper, with the exception of the zone of major linear structures. In the area of Kammon and on the Tran-Nin' plateau, the section begins with dark shales and micaceous sandstones containing Ordovician fossils. They are conformably overlain by the black and varicolored shales of the Gothlandian. Devonian and Lower Carboniferous deposits are widespread in the Annamit geosyncline. A continuous transition from the Silurian to the Devonian is thus far known only in the area of Kammon, where the Devonian is represented by the most deep-water facies. In other places the Devonian usually unconformably overlies the rocks beneath it, and is composed primarily of sandstones, shales and limestones. The Devonian section here begins with Upper Coblentzian or Eifelian deposits. Limestones and calcareous shales of the Coblentzian are known in the southeastern part of the geosyncline (in the area of Ron) and in the north of the Tran-Nin' plateau. Complete sections through the Middle Devonian limestones and shales are observed in the southeast, in the areas of Kui-Dat and Kham-Khet. Frasnian limestones have been discovered in the northern part of the geosyncline. Famennian deposits are very sparse, and have been fully established only in the area of Kui-Dat, where they are represented by limestones and shales. At a very small number of points, primarily in the southern half of the geosyncline, limestone and shale deposits of the Tournaisian have been found, merging into the Devonian by a gradual transition (Kui-Dat, Kam-Khet). The region of sedimentation again expanded in Visean times. The Visean deposits transgressively overlie the Devonian and Tournaisian, and in the west of the geosyncline are represented (from bottom to top): by argillaceous and calcareous shales, and by black and gray limestones containing pyrite. On the Tran-Nin' plateau there are shales and graywackes with interbeds of limestones of Visean age. West of Dien Bien Phu are black and varicolored sericeous shales, unconformably overlain by Upper Carboniferous deposits. These may be of Visean age [18]. The section through the Middle Paleozoic deposits of the geosyncline ends with Namurian limestones containing goniatite ammonoids, and also sandstones and conglomerates forming the uppermost parts of the Hercynian series.

As a whole, as compared to the western areas that border the Indochinese massif, the eastern and southeastern parts of the Annamit geosyncline are characterized by more stable areas of subsidence, sections of greater fullness and Middle Paleozoic facies deposited in

deeper waters.

The Middle Carboniferous epoch was the main climax of Hercynian folding. The folding was accompanied by the injection of a large number of alkaline granite intrusives. The large-scale intensive movements, represented by uplifts in Tournaisian and rapid subsidence in Visean times, were apparently the beginning of the Hercynian tectogenesis.

A new cycle of sedimentary accumulation began in early Moscovian times and continued to the end of the Permian and beginning of the Triassic, when large territories again became dry land.

The Upper Paleozoic deposits everywhere lie with erosional gaps and angular unconformities upon the various underlying strata. These are primarily limestones containing fusulines and brachiopods; their average thickness is 1200 m [14]. Mixed sand-clay and limestone facies were deposited in some places (Chan-Nin' and elsewhere). Marine sediments dated by their fauna as Lower and Middle Triassic are unknown in the Annamit geosyncline.

In Carnian times an enormous marine transgression occupied many regions of Indochina, including large areas of the Annamit geosyncline. At the end of the Carnian and beginning of the Norian ages and in Early Norian times, the territory of the Annamit geosyncline was subjected to intensive folding. This intensification of the tectonic movements (uplift in the first half of the Triassic and rapid transgression in the Carnian age), as in the case of the Hercynian tectogenesis, preceded the main climax of the folding.

Both the Hercynian and the Late Triassic movements compressed the rocks of the geosyncline into folds trending northwest. This circumstance, as well as the fact that the region of greatest subsidence in the Hercynian and Mesozoic cycles generally coincide, indicates a great inheritance of the Mesozoic stage of development in the Annamit geosyncline.

The unconformably overlying Late Mesozoic deposits are represented by continental and subcontinental formations, similar to the contemporaneous Indosinian deposits.

The zone of major linear structures of the Annamit geosyncline is located northeast of the above-described regions of the Annamit geosyncline proper (as defined by the French geologists. This occupies the interstream area between the Song-Ka and Red Rivers.

The linear structures of this zone may be divided into faulted and folded types. To the first category belong the Red River graben and the Thanh-Hoa fault. The large and very narrow Red River graben is the northeastern boundary of the zone of linear structures in the Annamit geosyncline, separating it from the differing major structures: the Northern Tonkin massif and the Tonkin geosyncline. The southeastern part of this zone of faults is covered by Quaternary sediments of the Hanoi Valley, and in the northwest continues far into Yunnan, along the Aylaoshan' range [9, 10]. This narrow structure, some 10 to 15 km broad, is filled with a 1000 m thick series of Neogene lacustrine and swampy coal-bearing deposits, lying directly upon the Precambrian rocks.

The Thanh Hoa fault ("the Thanh Hoa scar" of the French geologists) — the other major faulted linear structure of Tonkin — extends northwestward for a distance of more than 400 km from Piu Nang Santam to Thanh Hoa [13]. At the surface this fault is reflected by a zone of fractured rocks; along this extends a narrow chain of granitic intrusives and ultrabasic formations: peridotite ophiolites and serpentinites, bronzites, hornblendites and dunites.

In the same northwestward direction, along with the faulted dislocations, extend large complex linear folds, each of which stretches out for several hundred kilometers. These are (from southwest to northeast): the Song-Ka syncline, the Pu-Huat anticline, the Sam-Nea syncline, the Song-Ma anticline, the Song-Da syncline and the Hoang-Dien-Shang syncline with its associated Fan-Si-Pan chain in the north. The cores of the anticlinal structures are composed of Proterozoic and Caledonian metamorphic formations. Their flanks and plunges are transgressively covered by shales and limestones of the Devonian, Upper Paleozoic and Lower Mesozoic. The synclines between the anticlinal structures are filled primarily with Carnian marine shales and the unconformably overlying clastic rocks of the Norian stage.

The dislocations of the rocks composing these folded linear structures are very complex. A major role is played by flat-lying imbricated thrust sheets, which are especially frequent at the boundaries between the synclines and anticlines. The amplitudes of some of these reach several tens of kilometers ("The Black River thrust" — [16, etc.]).

This zone of linear structures is, in general, probably more uplifted than the remaining territory of the Annamit geosyncline, so that it contains truncated stratigraphic sections and numerous outcrops of Precambrian rocks.

The Western Cambodian geosyncline surrounds the Indochinese massif on the west, forming the Sankam-Peng, and the Daylaung-Dong-P'yafay mountain chains and the foothill upper reaches of the Nan River. Toward the north the folded formations of the geosyncline

are buried beneath the undulating folded Mesozoic deposits of Upper Laos.

Outcrops of ancient crystalline formations are known in several places among these Mesozoic rocks. In the south, in Western Cambodia, the crystalline basement is exposed north of Preas and in the area of Paylin [20], in two horst (?) outcrops, each of which has an area of several tens of square kilometers. The southern outcrop of ancient (Precambrian ?) crystalline rocks is composed primarily of mica, amphibole and other paraschists. Its trend is submeridional, conforming to the surrounding structures. In the southwestern part the ancient rocks are penetrated by intrusives of pre-Hercynian granites.

The metamorphic formations in the area of Paylin are represented mainly by "ortho" rocks, which trend primarily east-west. At their Northern boundary they are cut by a long, narrow intrusive of Hercynian granites, which was evidently introduced along a fault. In the northern part of the Western Cambodian geosyncline, the metamorphic rocks — gneisses and schists — are found southeast of Bangkok, among Triassic granite intrusives; the same rocks are exposed farther north, in the area of Pak-Laya, where they are very complexly folded and fractured. The metamorphic formations in the area of Pak-Laya are covered by Permian deposits; it is possible that they are of Precambrian age.

In the area of Paylin, and particularly in the vicinity of Preas and farther south, the crystalline formations are overlain, after a sharp angular unconformity, by non-fossiliferous quartzites, siliceous schists and marbles. By their lithology and stratigraphic position they have been tentatively assigned by J. Gubler [20] to the Cambrian-Silurian.[7] These deposits are transgressively and unconformably covered by Gubler's "shale-sandstone series": dislocated shales, marls and siliceous rocks such as jasper. The upper part of the series contains microfauna of the Upper Devonian-Lower Carboniferous, and on this basis has been dated by J. Gubler as Devonian to Lower Carboniferous. A possible chronological analogue of the shale-sandstone series is the Kankhanaburi series — the most ancient sedimentary rocks of Northern and Northwestern Siam. They are widespread in these areas and are composed of intensively crumpled, non-fossiliferous schists, phyllites and quartzites. Because of the complex folding, the thickness of the series cannot be accurately established, but it exceeds 1000 m. Its age has been determined by the geologists of Siam within broad limits (Silurian to Lower Carboniferous), on the basis of its stratigraphic position.

The Kankhanaburi series is unconformably overlain by the light-gray "Ret Buri" crystalline limestones, which are widespread along the western margin of the Korat plateau. In the north of Siam, in the basin of the Upper Nan River, the limestones occur as isolated erosional relicts, elongated in the northeastern direction. Here their thickness reaches 2000 m (in the Chiang-Dau district, [14]) and apparently increases westward. Permian fauna has been found in the lower part of the limestones; it is not impossible that the "Ret Buri" rocks also include Upper Carboniferous strata.

In Western Cambodia the Permian limestones unconformably overlie J. Gubler's sandstone-shale series. Here the most widespread formations are the limestones of the Kazanian stage, which often transgressively overlie the rocks beneath. A general uplift took place at the end of the Kazanian age and in the Early Triassic, so that Lower Triassic marine shales are known only in one place, south of Luang Prabang.

The Triassic and Jurassic deposits in Northern Siam are represented by a thick series of continental sandstones with basal conglomerates. These deposits are associated with mountain basins. In Western Cambodia there is also a thick series of Mesozoic sandstone deposits, overlying the older rocks after an erosional gap. Upper Triassic marine formations are preserved in the northwestern part of Siam (the Kamavkala series of limestones - [14]).

In the west of Northern Indochina, north of the Western Cambodian geosyncline, are the areas of most prolonged subsidence in the Mesozoic — the region of Upper Laos ("the Upper Laos syncline" - [13]). Here Mesozoic Indosinian deposits are widespread on the surface. Marine deposits are considerably more prominent. In Upper Laos one may distinguish several submeridional large synclinal structures separated by uplifted areas. On the whole, the western part of Upper Laos, the Liu region, is relatively downwarped, whereas the eastern margin is uplifted. In the Nam-O River valley, along the eastern edge of this region, the section begins with the upper part of the Carboniferous and Permian. It is composed primarily of sandstones and shales and, more rarely, of limestone rocks. Andesitic tuffs are prominent in the composition of the Upper Carboniferous deposits. Above these there is a transgressive deposition of Ladinian (?) and Carnian clastic formations. These in turn are unconformably overlain by the sandstones and shales of the Upper (Jurassic-Cretaceous) Indosinian deposits, associated

[7] Paleontologically dated Cambrian and Ordovician deposits are known only in the peninsula of Siam, where they are represented by thick strata of sandstones, shales and dark limestones [14].

th the synclinal structures. Redbeds and coal-aring facies are abundant in these Jurassic-retaceous deposits. The upper chronological undary of these marine deposits has not been curately determined; in the western part of pper Laos there are Liassic lagoonal forma-ons, and perhaps also even higher stratigraphic vels. The visible thickness of the pre-Upper riassic deposits alone is about 1000 m. The ickness of the Upper Indosinian deposits ceeds 600 m.

The lower part of the Mesozoic deposits has een considerably folded, and is apparently a ontinuation of the folds of the Western Cam-odian geosyncline, which south of east-west end of the Mekong River is buried beneath pper Indosinian deposits. The latter occur as entle undulating folds. An intensification of e folding is observed in the west, in the Liu egion. Post-Liassic movements probably ayed a certain role here.

On the east, Upper Laos is bordered by a rge zone of faulted dislocations, extending arallel to the meridian from the northern ter-inus of the Indochinese massif to the Pu-Isi-ung intrusives. Farther to the north, within e territory of Yunnan, the zone is continued the longitudinal faults of the Kam-Yunnam xis [10]. This zone of faulted dislocations has een fixed by numerous intrusives, areas of recciated rocks and surface outcrops of ancient rmations. It is located at the junction between e Annamit and Western Cambodian geosyn-lines and represents a typical shaarung. Far-her west, in the territory of Upper Laos, paral-el to the shaarung, extends a series of smaller aults which are frequently marked by igneous ikes [18].

The large complex folds of the Tonkin geo-ynclinal zone surround the Northern Tonkin assif on three sides, following its outlines. n the east and south this zone is bordered by narrow, elongated band of igneous formations, hich rapidly changes to a north-northeast rend in the area of Lang Son. This belt of in-rusives is probably associated with large faults f equatorial and submeridional trends. The ores of the complex alternating synclinal and nticlinal folds of the Tonkin geosyncline con-sist of Precambrian and marine Paleozoic rocks.

Moreover Devonian rocks evidently uncon-ormably overlie the older rocks. On the lanks of the anticlines and in the synclines here are shales and sandstones of the Upper Paleozoic and Triassic, transgressively over-ying the rocks beneath. From the beginning of the Jurassic period there was no marine sedi-mentation in this area.

The Paleozoic and Lower Mesozoic deposits are crumpled into complex folds. The major folds are characterized by rapid sinking and reemergence of their plunges (the "Kok-Kso and Ien-Lak anticlinal arches" and others).

South and southeast of the Tonkin geosyn-clinal zone lies the extensive Mon-Kay region, which underwent subsidence in the Early Meso-zoic era. Within its territory there are wide-spread marine limestones, sandstones and shales of the Triassic, and also Rhaetian-Liassic littoral-marine and continental deposits. The latter sometimes contain coal.

The above-described formations of the Mon-Kay region are crumpled into isoclinal folds, trending east-west in the Nan'-Nin' region. The trends of the structures in the Mon-Kay region cut across those of the folds in the Ton-kin geosynclinal zone; this also suggests the probability of faulted dislocations between them.

The formatijon of the superimposed basins — the Cochinchin and the Anh Diem — is asso-ciated with the stage of regional uplift at the beginning of the Triassic. The east-west Anh Diem basin, which takes its name from the city of Anh Diem, is superimposed on the meta-morphic formations of the Kontum massif, cut-ting off its northern part. The visible section through the basin is composed of Rhaetian-Liassic rocks more than 2500 m thick [14, 21]. The Rhaetian deposits are represented by coarse clastic material and coal-bearing shales. The siliceous puddingstones, sandstones and cal-careous shales belong to the Liassic. Marine fauna has been found at the base of this series, testifying to a brief transgression of the sea at the beginning of the Liassic.

The deposits described above have been crumpled into folds trending east-west. It is interesting to note, however, that the marine Liassic deposits southwest of the above-mentioned outcrops, and already within the limits of the Indochinese massif, (the Attope district) are flat-lying.

The Cochinchin basin ("The Cochinchin trench" of the French geologists) surrounds the Southern Annam massif on the northwest. This basin is filled with Lower Mesozoic deposits, covered by Indosinian continental deposits and fields of Cenozoic basalts. The most ancient sedimentary rocks in the Cochinchin basin have been found along its eastern edge, at the boun-dary with the Hercynian structures of Southern Annam. These are Late Carboniferous-Permian basal conglomerates, sandstones and limestones containing fusulines. In the Late Paleozoic, however, this basin, as the last structure to be formed, still did not exist, inasmuch as synchronous deposits of the same facies exist on the Dzhiring plateau within the Southern Annam massif. In the later Permian and beginning of the Triassic the area of the basin was uplifted; dacites and rhyolites of this age are widespread in the basin. Intensive

subsidence began in the Triassic: Middle Triassic sandstone-shale deposits with floral remains occur unconformably. Upper Triassic rocks are represented by clay shales, sandstones and, at the top, by redbeds. One may observe a general coarsening of the clastic material toward the Southern Annam massif, from which it was derived. Liassic deposits are known in continental ("upper sandstones") and marine (clay shales) facies. Spotty occurrences of these marine rocks occur in the south and in the northern part of the basin, along the Song-Ba River valley [26].

The Mesozoic deposits that fill the Cochinchin basin are crumpled into folds forming a ring around the Southern Annam massif. These folds are primarily isoclinal, with angles of dip on the flanks of several tens of degrees [25].

Thus two main phases of folding are fixed in the geosynclinal zones of Indochina: a Hercynian (Middle Carboniferous) and a Mesozoic (Upper Triassic) phase. Hence the tectonic map within the geosynclinal zones correspondingly shows: a Precambrian metamorphic basement, a lower structural stage embracing the pre-Middle Carboniferous deposits, and an upper structural stage corresponding in time to the post-Hercynian phase and to the period of Mesozoic folding. The upper stage is divided into substages: a lower substage embracing the Upper Paleozoic, a middle substage that includes the Mesozoic deposits (up to the time of the Late Triassic folding) and an upper substage of Rhaetian-Liassic deposits in the north (Upper Laos). Unfortunately in this article it has been impossible to show a graphic subdivision of the lower and middle substages, so that they are shown only in the legend. The need for such a subdivision, however, is confirmed by the fact that the superimposed basins appeared during the time between the formation of the lower and middle substages. These peculiar structures are indicated by special signs on the map.

The Quaternary basins — the Mekong, the Menam, the Vientiane and the Hanoi basins — are the areas of present-day sedimentation. They are reflected in the topography as intermontane basins and inherited valleys of major rivers.

The basins are filled with alluvial-proluvial, deluvial and littoral-marine formations of considerable thickness: in the southern part of the Mekong basin (close to Kokong) and in the Menam basin (close to Bangkok), holes were drilled to depths of 387 and 300 m respectively, but failed to extend in depth beyond the Quaternary deposits. These basins overlie the essentially different tectonic elements of the ancient structures, and are thus superimposed formations. The most common igneous rocks in Indochina are granitoids. These are primarily synorogenic, Hercynian (γ_1 on the map) and Upper Triassic (γ_2) alkaline granites. The formation of the series of hypabyssal rocks (the series of andesites — dacites-rhyolites [π]) is dated mainly at the end of the Paleozoic and early part of the Triassic — that is, the time of general uplift.

The youngest igneous rocks in Indochina are the Pliocene-Quaternary basalts, which belong to the platform stage of development of this entire territory.

In conclusion, it must be said that the Early Mesozoic structures of Indochina differ considerably in the age of their folding, and in certain other characteristics (the nature of the Paleozoic basement, the volcanic activity, the fullness of the section, etc.), both from the Mesozoic structures of many other regions of the Circumpacific belt and from the "normal" geosynclines, as they are classically described.

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ON THE PROBLEM OF THE GENESIS OF PLATFORM STRUCTURES OF THE II AND III ORDERS[1,2]

by

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Analysis of data on uplifts in the Saratov region forms the basis for a description of the process of formation of platform structures of the II and III orders. The appearance of such structures is believed to be due to vertical displacements of blocks of the crystalline basement, these displacements being not vertical, but along the inclined planes of faults.

Proceeding from his description of the genesis of platform structures, the author makes some remarks on the source of the tectonic movements on the platform and draws a distinction between tectonic movements of a regional character and the movements that form the structures of the II and III orders.

* * * * *

The structures of the Russian platform are commonly divided, according to their scale, into three groups — structures of the I, II and III orders.

Anteclises and syneclises are structures of the I order. Structures of the II order are of smaller size and have clearly reflected contours. They are usually separate, but in certain places, for example in the area of the Saratov dislocations, they are closely grouped, forming a series of similar structures. The lack of parallel trends is typical. Positive structures of the II order are usually accompanied by negative structures of the same order; these are not, however, similar in form and scale. The structures of the II order are superimposed on various elements of the structures of the I order. At one time A. D. Arkhangel'skiy suggested the name "arches" for the positive forms of these structures, and this name is most frequently encountered in the present literature; according to M. M. Tetyayev, these are "domical uplifts", according to V. V. Belousov, they are "discontinuous folds"; and according to N. S. Shatskiy, they are "placanticlines".

Uplifts of the III order are sharply asymmetrical, domical or brachyanticlinal swellings usually situated on structures of the II order. In the literature these forms are known by the names "structures of the III order", "uplifts of the III order", "local uplifts", "structures", "domes" and "brachyanticlines".

None of the above-listed names for structures of the II order reflect either their genetic or their morphological features. Throughout the rest of this article these structures will be called "flexural folds". For positive structures of the III order it is believed most suitable to use the name "uplifts of the III order". The basis for the names used by this writer will be explained below. It should be added that throughout the remainder of this text, the expression, "structures of the II order", will be used for tectonic structures as a whole, representing combinations of positive and negative structural forms.

A correct answer to the question of the origin of platform structures of II and III orders will be of great practical and theoretical importance, particularly in locating and prospecting for a number of minerals and other resources associated with sedimentary rocks — especially oil and gas. The solution to this problem will also provide a more circumstantial and definitive discussion of the nature and character of tectonic movements in the earth's crust. N. S. Shatskiy [11], discussing the importance of the genesis of platform structures, as early as 1945 wrote: "The problem of the genesis of the above-described dislocations, as of placanticlines as a whole, is still far from being finally solved.

[1] K voprosu o genezise platformennykh struktur II i III poryadkov.

[2] Lower Volga Branch of VNIGNI, Saratov.

his is one of the most urgent theoretical and ractical problems in the geology of platforms, nce its solution will provide a more rational asis for the location and prospecting of oil-earing structures."

Almost all of the numerous papers devoted the tectonic structure of the Russian platform one degree or another treat of the genesis of atform structures of the II and III orders. evertheless the views expressed, up to the resent time, of the genesis of such structures o not explain a number of the most typical and ncontroversial features of the latter, specifically:

1) the clear asymmetry of uplifts of the II and I orders — since there are no symmetrical plifts of the II and III orders; although certain eologists describe these uplifts as being symmetrical, in the overwhelming majority of cases is is explained as being due to their insufficiency of original factual data, perhaps complicated by their incorrect conceptions of the genes of such uplifts;

2) the location of uplifts of the III order on e uplifted flanks of flexural folds and always the immediate vicinity of flexural steps, so at the steep flanks of uplifts of the III order ecessarily merge into the flexural steps, hereas the gently sloping flanks merge into e monoclinal, uplifted flanks of the flexural olds.

The solution to the problem of the genesis of latform structures of the II and III orders has, the present writer's opinion, been greatly indered by the widespread currency of such istorical-geological methods of analysis as are ased on the idea that the thicknesses of sedimentary rocks depend only on tectonic movements, and that tectonic subsidence is completely and ideally compensated by sedimentaon. It is frequently forgotten that the final nd presently fixed thicknesses depend also on number of other factors. Moreover in view f the oscillatory and wave-like nature of the ectonic movements of the earth's crust, it is ften supposed that uplifts of the II and III orders re formed gradually and continuously. Many eologists are inclined to believe that the emerence and formation of uplifts of the II and III rders are not associated with faults in the crysalline basements of platforms.

In recent times an increasing number of eologists working on the platforms are coming o the conclusion that the platform structures in he sedimentary complex originate and are ormed by the action of displaced blocks of the rystalline basement. The influence of blocks f the crystalline basement on the formation of latform structures was described as early as 1894 by A. P. Karpinskiy [3], in 1896 by A. P. Pavlov [8], in 1945 by N. S. Shatskiy [11], B. A. Mozharovskiy [4], P. Ye. Offman [6, 7], and later by other writers. The above-mentioned investigators have had various views on the source and direction of the tectonic forces that produced the faults in the crystalline basement, breaking it up into individual blocks and displacing the latter relative to each other, but they all conceived of these fractures and faults as being either vertical or nearly vertical. On the basis of such conceptions it was possible to give a more-or-less reliable explanation of the appearance of certain uplifts of the II order, which had symmetrical box-like forms, but the existence of the numerous uplifts of the III order, which are most often genetically closely associated with uplifts of the II order, was not satisfactorily explained.

At the present time many of the districts in the Volga-Ural oil-bearing region have been quite thoroughly drilled. Quite a large amount of factual information has been accumulated on a number of the oil-bearing uplifts of these districts, providing a detailed view of their geologic structure and suggesting reliable explanations of their genesis. One such area — that of the Saratov dislocations — lies on the buried eastern flank of the Voronezh anteclise; the southern termination of the Sura-Moksha flexural fold approaches close to this point from the north.

The saratov dislocated region consists of a group of seven folds — structures of the II order (Figure 1). In the southern part of the area lies the Volga-Medveditsa flexural fold, in the west is the Sleptsov-Ozerkov fold, in the central part the Khlebnov fold, in the northwest the Orkino-Gremyachka fold, in the northeast the Teplovka-Irinovka flexural fold, and perpendicular to the latter is the Karabulak flexural fold. Uplifts of the II order separate the areas of tectonic subsidence of different shapes and sizes from each other.

The folds just described above are asymmetrical, and are disposed relative to each other without any definite orientation, their amplitude through the Mesozoic and Cenozoic deposits ranging from 240 to 600 m or more. Through the older deposits, the amplitudes of the folds are considerably greater. On the uplifted flanks of the various flexural folds the Mesozoic rocks dip at angles from 1° to 5°, and on the flexural steps of the folds at angles from 15 – 35°. In the Paleozoic deposits the angles of dip increase to 55 – 60°

The flexural steps of the folds form undulating belts in plan view. On the uplifted flanks of these chain-like belts lie uplifts of the III order, pressing against the flexural steps. The uplifts of the III order are separated on the map by depressions of 30 – 50 m, corresponding to the detailed corrugations of the flexural steps. The steep flanks of the uplifts of the III order merge

FIGURE 1. Structure-contour map of the region of the Saratov and the southern part of the Sura-Moksha dislocations, at the base of the Barremian stage. Structure-contour interval 40 meters.

into the flexural steps, and their gently sloping flanks into the monoclinal uplifted flanks of the flexures.

Structural maps of the area of the Saratov dislocations, based on the Carboniferous deposits and the carbonate rocks of the Upper Devonian, are almost identical to those based on the Mesozoic and Cenozoic deposits. There is only a certain increase in the angle of dip of the rocks with increasing depth. On the other hand the structural map of the Middle Devonian deposits, although they have been little studied in the area of the Saratov dislocations, differs sharply from those drawn upon the overlying, younger deposits. A sharp discrepancy between the structures in the Middle Devonian and those in the younger deposits is observed, for example, in the Sokolovogorsk uplift (Figure 2). The uplifts of the III order, as reflected in the Middle Devonian, are for the most part buried, and have smaller sizes but more distinct contours than those in the Mesozoic and Cenozoic deposits. But the regular and sharp asymmetry in the platform uplifts of the II and III orders is also typical of the Devonian buried uplifts.

The area of the Saratov dislocations contains

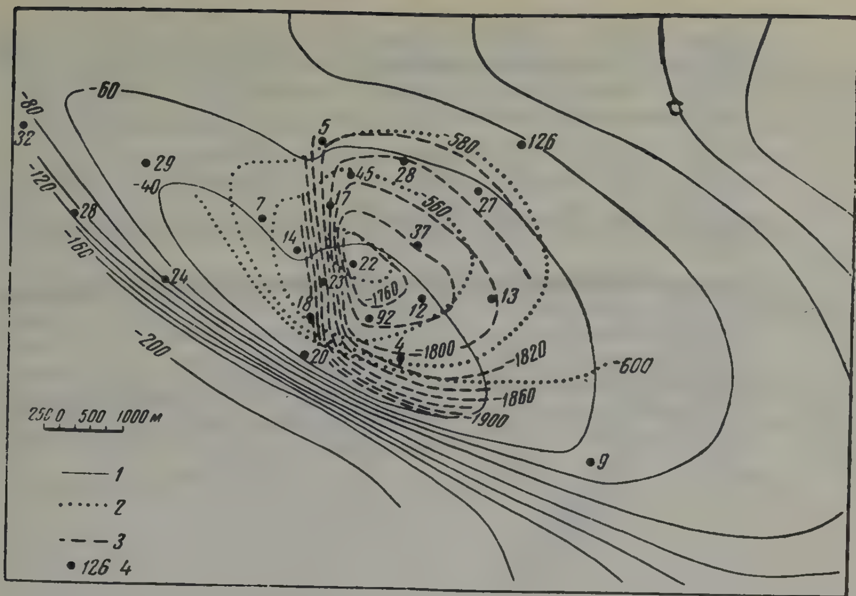

FIGURE 2. Comparison of structural maps of the Sokolovogorsk uplift, based:

1 -- on a datum plane in the Callovian stage, 2 -- on a datum plane in the Vereyan deposits, 3 -- on the surface of the Givetian stage, 4 -- numbers identifying drill holes. Structure contour interval 20 meters.

ıany thoroughly drilled uplifts of the III order, ontaining the same or very similar structures. ifferences in these structures along various tratigraphic levels are noted only in those ases in which the formation of the uplift difered in the number of its phases.

The Sokolovogorsk uplift, with its complex tructure, and the Gusikho uplift, with its simle structure, will be described below.

The Sokolovogorsk III order uplift in the icinity of Saratov, on the uplifted flank of the 'olga-Medveditsa flexure, is sharply asymmerical; its steep flank in the Mesozoic deposits nerges into the flexural step and its gently loping flank into the uplifted flank of the flexre. The dimensions of the uplift and the relaionships of its structures in the Devonian, 'arboniferous and Mesozoic deposits are illusrated in Figure 2. Its steep flanks in the Mesooic rocks dip at angles of 18 – 20°, up to 25° n the Carboniferous rocks, and up to 38° in he Middle Devonian. The gently sloping flanks lip at 30' in the Mesozoic deposits and 2° 30' in he Middle Devonian rocks.

Within the uplift the stratigraphic levels of he section are composed of terrigenous and arbonate rocks. The lithologic composition of he carbonate strata is constant, whereas in he terrigenous levels the sands are frequently eplaced laterally by siltstones and clays, and he clays in turn by siltstones and sands.

The thicknesses of the stratigraphic layers within the uplift (Figure 3) change to one extent or another, but these changes are generally not great and show no regular relationship to the structural form of the uplift. Such small variations in the thickness are explained either by certain peculiarities of the process of sedimentation, or by uneven compaction of the sediments during diagenesis or, finally, by regional conditions that have no connection with the formation of the given uplift of the III order. The geologic section clearly shows the parallel occurrence of the stratigraphic levels. There are no isopach maps corresponding to the structural maps for each stratigraphic level.

The changes in the thickness of the Lower Shchigrov beds in the Sokolovogorsk uplift are in direct relationship to the structural forms. The accumulation of sediments in Early Shchigrovian times took place simultaneously with the origin and formation of the Sokolovogorsk uplift. Correlation sections through the uplift in various directions show a change in the lithologic composition and the thicknesses of the individual beds in the lower two-thirds of the Lower Shchigrovian strata, from the center to the periphery of the uplift. The strata composing the upper third of the Lower Shchigrovian beds, both in the crest and on the flanks of the uplift, are constant in composition and thickness.

The increase in the thickness of the Myachkov

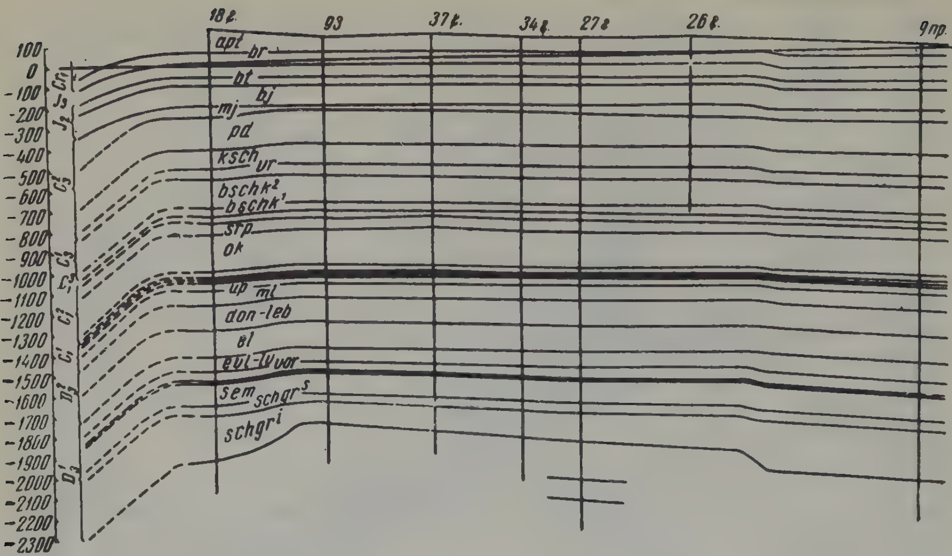

FIGURE 3. Geologic section through the Sokolovogorsk uplift along the line from drill holes 18 to 9, encompassing deposits from the Lower Shchigrovian in the Frasnian stage to the Aptian in the Lower Cretaceous.

stratum from the crest to the flanks of the uplift indicates that this stratum had already been dislocated before the erosional gap in pre-Middle Jurassic times. As a result of this erosion, this stratum is thinner in the crest of the uplift than in the areas of tectonic subsidence adjoining it.

There are no data on the formation of the Sokolovogorsk uplift before Early Shchigrovian times. For this reason its history may be reconstructed only from the beginning of the second half of the Givetian age.

In the second half of the Givetian age the Sokolovogorsk uplift did not exist. At that time, this area was subjected only to the action of regional tectonic movements, and the Sokolovogorsk uplift began to be formed only at the beginning of the interval of time represented by the Lower Shchigrovian age to the end of the Paleozoic, the tectonic movements forming structures of the II and III orders were not manifested in the Sokolovogorsk area.

At the end of the Paleozoic, the Sokolovogorsk uplift again underwent tectonic movements forming the structures of the II and III orders. But this second phase in the formation of the uplift was less intensive than the first (Figure 3).

The third and concluding phase in the formation of the uplift occurred during the Miocene and beginning of the Pliocene. Throughout the entire Mesozoic and Paleogene, there were no structure-forming movements acting upon the Sokolovogorsk uplift. The third phase in its formation, which took place in post-Mesozoic times, is marked by the angular unconformity between the Carboniferous and the Mesozoic deposits and by the dislocation of the latter (Figure 3).

The Gusikho uplift of the III order lies upon the uplifted flank of the Sura-Moksha flexure (Figure 1). The long axis of this sharply asymmetrical arch extends from southwest to northeast. The steep flank of the uplift merges into the flexural step (Figure 4). The angles of dip of the Mesozoic rocks on the steep flank do not exceed 15°, but in the Carboniferous deposits they reach 20° and, at the top Givetian stage, increase to 40°. The gently sloping flank of the uplift merges into the uplifted flank of the flexure and here the rocks, from Devonian to Mesozoic inclusive, dip northwestward at an angle of 1°10'. The surface of the crystalline basement (Figure 5) is also inclined toward the northwest at an angle of 1°10'.

The lithologic composition and the thickness of all the stratigraphic levels in the section within the Gusikha uplift do not change. The insignificant changes in the thickness (no more than several meters) of any given stratigraphic level are the result either of regional tectonic movements or else of differential compaction of the sediments during diagenesis. The unevenness of the ancient surface of erosion may have had some effect on the thickness of individual strata. The gaps in sedimentation and the absence from the section of certain stratigraphic levels are

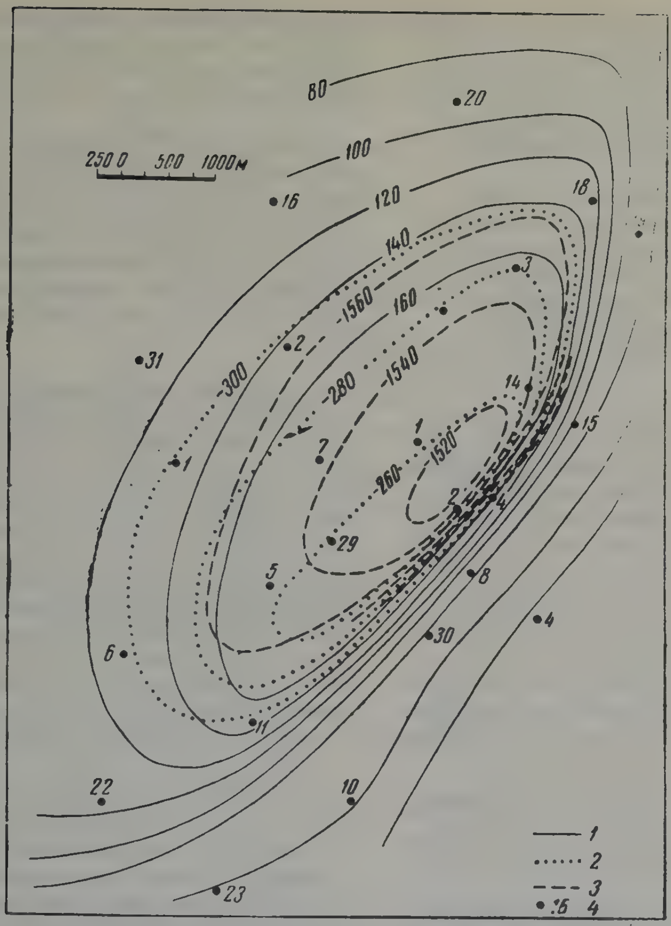

FIGURE 4. Relationships between the structures of the Gusikha uplift in Devonian, Carboniferous and Mesozoic deposits.

Structure contours: 1 -- at the base of the Aptian stage, 2 -- at the base of the Vereyan strata, 3 -- at the top of the Givetian stage, 4 -- drill holes.

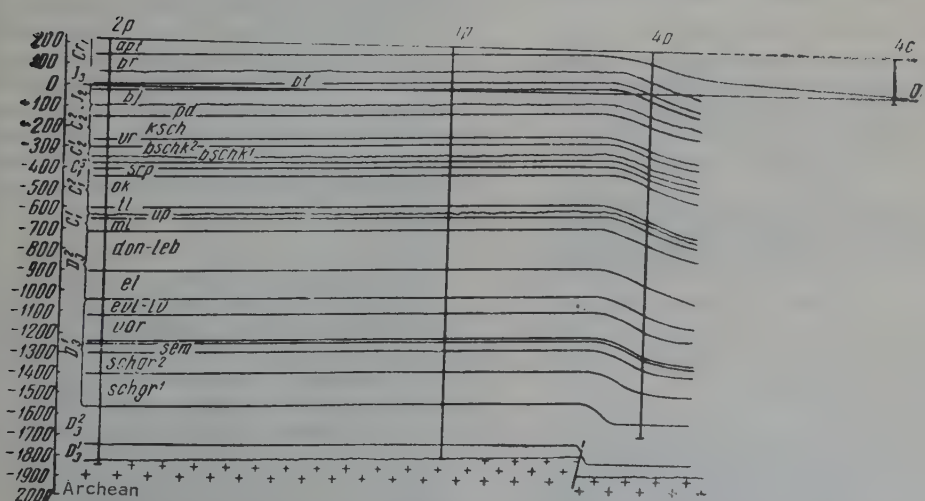

FIGURE 5. Geologic section through the shorter axis of the Gusikha uplift.

explained not by discontinuities in the process of formation of the uplift, but by regional tectonic movements. Beneath the ancient erosional surfaces, throughout all the area of the Gusikha uplift, the residual thicknesses are equal or else change very slightly at various points.

The conformable occurrence of all the stratigraphic levels in the Gusikhinsk uplift testifies to the existence of a single phase of formation of this uplift in the Miocene and beginning of the Pliocene, since the Paleogene deposits preserved on the steep flank of the Gusikha uplift are dislocated together with the Mesozoic deposits.

The morphology of uplifts of the II and III orders, the relationships between the structural forms at various levels and between various uplifts, and also their positions relative to structures of the I order in different parts of the Russian platform, have been described in varying detail by N. S. Shatskiy (11), V. V. Belousov (2), P. Ye. Offman (6, 7), N. Yu. Uspenskiy (10), V. D. Nalivkin, L. N. Rozanov, E. E. Fotiadi (5) and many other geologists. Detailed study of the available data on the tectonic uplifts of the II and III orders in the Saratov and adjoining areas suggests that the following of their characteristics are to be considered regular features:

1) the lack of any definite orientation of the structures of the II and III orders relative either to each other or to the structures of the I order;

2) the asymmetry of all uplifts of the II and III orders, without exception;

3) the disposition of uplifts of the III order, complicating the structure of the crests of uplifts of the II order, only near the flexural steps of the latter, the steep flanks of the uplifts of the III order also merging into the flexural steps;

4) the displacement of the crests of a given uplift throughout the older deposits only in the direction of the gently sloping flank; in rare cases, moreover, the crests are also displaced along the long axis of the uplift;

5) the decrease in the areas of uplifts of the II and III orders with depth, accompanied by an increase in the degree of dislocation of the rocks;

6) interruptions in the process of formation of structures of the II and II orders occurring in one or several phases.

A correct solution to the problem of the origin of platform structures will require a large amount of data on the structure and the surfaces of the crystalline basement, and although such material is not yet available for the Russian platform, it is nevertheless possible to say that the crystalline basement played a decisive role in the formation of platform structures of the II and III orders.

Of the regularities enumerated above, the first five apply to platform structures of the II and III orders; they may be explained only on the basis that the crystalline basement is broken up into individual blocks of different shapes and sizes, which are displaced relative to each and thus also displace the mantle of sedimentary rocks overlying them in vertical directions.

There is no doubt of the existence of a very dense net of faults in the crystalline basement. This has been proved by thorough investigation of the extensive areas of crystalline rocks of the Baltic shield. There the fractures, without any definite orientation relative to the points of the compass, break the crystalline massif into individual areas—blocks whose areas are measured from a few square kilometers to several hundred square kilometers. The fracture planes usually dip steeply, and their strikes form broken or curved lines; only in individual cases do they form straight lines. According to A. A. Polkanov (9), the angles of dip of these fractures vary from 70 - 90°

The appearance of sharply asymmetrical structures in the sedimentary complex is possible only as a result of displacements of the crystalline basement of such a nature that one edge of a block will be necessarily uplifted to a greater height than the other edges of the same block. In other words, after the vertical displacements of the block, its surface must be inclined (See Figure 5). It is quite clear that the individual blocks could not occupy such positions if the fault planes between them were strictly vertical. The surface of the displaced blocks can occupy an inclined position only if the fractures form angles less than 90° with the horizontal plane, and in the vertical plane (perpendicular to the strikes of the fractures) form parabolic curves (see Figure 6b). The fault planes dip at steep angles at the surface of the crystalline basement, but the angle of dip gradually decreases with increasing depth, until the fracture disappears in the zone of plastic rocks below the basement.

This conception of the formation of faults thoroughly explains the structures of the II order that appear in the sedimentary complex through the displacement of blocks of the crystalline basement. The ends of two adjacent blocks, displaced vertically relative to each other, correspond to flexural steps in the sedimentary complex. The inclined position of the surfaces of the basement blocks explains the monoclinal mode of occurrence of the sedimentary rocks overlying them. Two such

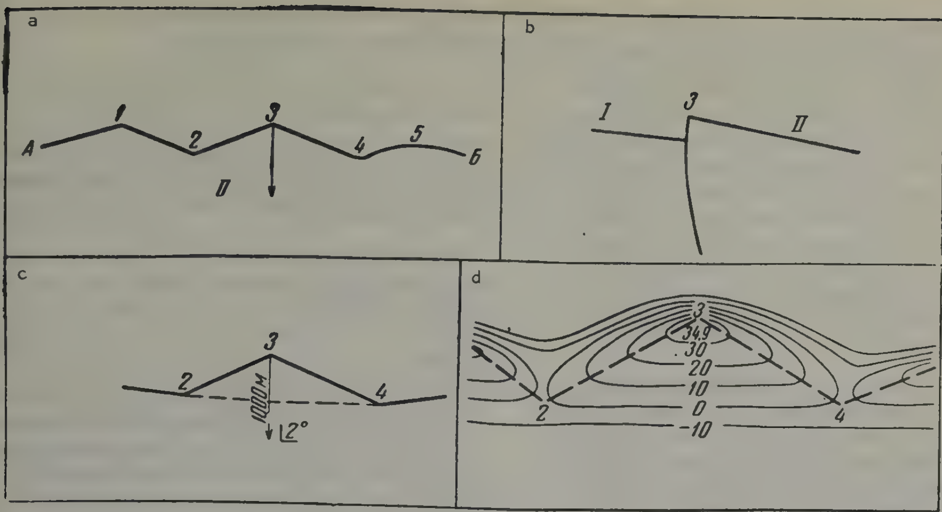

FIGURE 6. Diagram showing the formation of structural forms as a function of the formation of fractures in the basement complex.

reas, connected by a flexural step, will form typical flexure, which is a platform structure f the II order. Thus the sharp asymmetry f the platform structures of the II order is the nevitable result of their origin and of the proess of their formation.

The appearance and development of uplifts f the III order is most often indistinguishable rom the origin of structures of the II order, nd occurs as a result of the movements of hese same blocks of the crystalline basement.

As mentioned above, the planes of the faults n the crystalline basement form broken or curved lines on the map. Their formation is as follows: let us suppose that the line AB (Figure 6a) indicates a fault in the surface of the crystalline basement that separates the two blocks I and II. If block II is displaced by tectonic forces upward relative to block I along the fault plane, which has the form of a parabolic curve in the vertical profile (Figure 6b), the surface of block II will assume an inclined position. Thereupon the reentrant and emergent parts of its edge, designated by the figures 1, 2, 3, 4, and 5 on Figure 6a, will be uplifted to various heights. Points 1, 3 and 5 on the edge of the block, when the surface is inclined in the direction indicated by the arrow in Figure 6a, will be uplifted to greater elevations than points 2 and 4 on the same edge of the block. The greater the angle of inclination taken by the surface of the block of crystalline basement, the greater will be this difference in uplift.

If the surface of the upward displaced block is inclined at an angle of 2°, as shown in Figure 6c, and point 3 on the edge of the block is at a distance of 1000 m from the line connecting points 2 and 4, the edge of the block at point 3 will be elevated relative to the edge at points 2 and 4 by a distance equal to $1000 \times \sin 2° = 1000 \times 0.0349 = 34.9$ m.

In its upward movement, the block raises the overlying sedimentary rocks by the same height, but since various parts of the same block after its displacement will be uplifted to different heights, the sedimentary rocks occurring over these points will also be displaced upward by various heights. Corresponding structural forms will appear in the sedimentary rocks in relation to these differential movements.

Any particular stratum in the sedimentary series lying above the surface of the displaced blocks will repeat the configuration of these blocks in less distinct form. In our example (Figure 6c), at points 2 and 4 the given stratum will occur at the same elevations, and at point 3 it will be 34.9 m higher. If the elevation of the datum plane is taken to be zero at points 2 and 4, at point 3 this stratum will have an elevation of 34.9 m. From three points one may construct a structural map (Figure 6d) typical of platform uplifts of III order.

The structure contours on the structural maps of uplifts of the II and III orders, constructed according to data from structural geologic surveys or from drilling, usually appear more convoluted, whereas the shapes of the uplifts are more rounded. In some cases this is the result of an insufficiency of

data and of an attempt on the part of the author of the map to smooth out the angularity, but in other cases this is quite well-founded, since beds of rocks that retain their absolute thicknesses even within the areas of small uplifts of the III order are not encountered in nature. Moreover the inclinations of the surfaces of the blocks of the crystalline basement may be orientated in different directions and at different angles, whereas the structural map in Figure 6b was drawn on the assumption of a horizontal datum plane up to the moment of vertical displacement of the blocks of the crystalline basement.

When a block of the crystalline basement is uplifted upward relative to all the other blocks and its surface assumes an inclined position, the irregularities in the fault along the less uplifted edge of the block will cause the appearance in the sedimentary series of such structural forms as plunging tectonic noses and troughs.

All the uplifts of the II and III orders in the Saratov region, like the Sokolovogorsk and Gusikha uplifts described above, were formed discontinuously, in separate phases measurable in terms of geologic ages. These phases were separated from each other by incomparably greater lengths of geologic time than the duration of each phase. For example, in the Saratov region the phases in the formation of the uplift occurred during the Lower Shchigrovian times of the Frasnian age, in the Zadonsk-Yeletsk time of the Famennian age, in the Ufa age of the Permian period and in the Miocene and beginning of the Pliocene, whereas during the long times between these epochs there were no movements forming structures of the II and III orders. The phases in their formations were sometimes accompanied, and sometimes not accompanied, by processes of sedimentation.

The data on the structures of the II and III orders in the Saratov region compel us to disagree with the commonly accepted, but absolutely incorrect conception, according to which the formation of these structures occurred in a slow and continuous evolution accompanied by sedimentary accumulation.

It is also necessary to distinguish tectonic movements of a regional character from the movements that form structures of the II and III orders. Many geologists fail to make such a distinction, so that concepts have appeared of the multiphase nature of the formations of structures of II and III orders; each interruption in the process of sedimentation is taken to be a phase in the formation of such structures. But the factual data contradict this concept. As an example, we may cite the thicknesses (in meters) of a number of stratigraphic levels of the Carboniferous rocks in the Sokolovogorsk area (Figure 2), which indicate gaps in sedimentation.

This table shows clearly that the interruptions in sedimentation at the end of the Tournaisian, Namurian and Bashkirian ages were not accompanied by the process of formation of the Sokolovogorsk uplift. The same applies to all the other uplifts of the Saratov region.

The movements forming structures of the II and III orders are genetically associated with regional tectonic movements. Both are the results of one and the same cause—the overall geotectonic process. But not all manifestations of regional tectonic movements have been accompanied by movements involved in the formation of structures of the II and III orders. On the basis of the above-described origin of platform structures of the II and III orders, the cause of the movements occurring on platforms both those of a regional nature and those forming structures of the II and III orders, appears to be compression of the interior mass of the earth. Whether this is due to cooling of the earth, or to a continuing process of solidification of the interior parts of the earth of a result of differentiation of its material according to specific weight, as O. Yu. Shmidt's cosmogenic hypothesis would have it, the outer shell of the earth, representing the crystalline basement and the overlying sedimentary complex, must in either case be continuously adapting itself to the decreasing volume of the internal mass of the earth. This process causes a buckling of the earth's shell, manifested in the successive appearance and disappearance of convexities and concavities in it. Tangential stresses also arise in this process.

The upwarped and downwarped parts of the earth's crust were initially quite extensive and had smooth and scarcely noticeable transitions between them With the course of time the sizes of these areas gradually decreased, whereas their amplitudes increased and the tangential stresses in the earth's crust increased simultaneously. This increase in the intensity of the buckling of the earth's crust and in the magnitude of the tangential stresses continued until the limit of plastic deformation of the rocks in the crystalline basement had been exceeded; thereafter the latter began to be broken into individual blocks of different sizes and shapes. The fractures in the crystalline basement, inasmuch as they appeared under the conditions of the continually acting tangential stresses, could not be strictly vertical. They dip steeply and, in the vertical projection, are represented by parabolic curves which smooth out with increasing depth.

After the crystalline basement had been broken into individual blocks, the latter were

Stratigraphic Units	Marginal drill holes				Drill holes within arch	
	5	18	9	36	93	98
Cherepetskian strata	13	15	14	15	13	9
Coal measures	8	11	10	11	12	13
Naumurian stage	46	33	13	32	37	44
Lower Bashkirian substage	30	37	38	44	41	41
Upper Bashkirian substage	117	144	124	125	113	126

isplaced vertically relative to each other by ie tangential stresses along the parabolically urved fracture planes and began to uplift the edimentary rocks overlying their surfaces. he tangential movements are transformed ito vertical and radial movements. Structures f the II and III orders arose in the sedimentary omplex under the action of the displaced locks of the crystalline basement, in accordnce with the dimensions, the shape and the mplitude of displacement of the latter. The ormation of these structures has been escribed above.

The tangential stresses in the crystalline asement, which had been relieved by the novements of the blocks in the vertical direcion, again began slowly to increase. The rocess described above was thus repeated.

Inasmuch as the tangential stresses again egan to increase after being once relieved, everse movement of the blocks already dislaced upward was impossible. In a reverse novement of the earlier uplifted blocks, the islocated sedimentary rocks would necessarily lso have had to subside. In this subsidence, he earlier structural forms already created n the sedimentary complex would either have lisappeared, or have been broken up into small ragments. The first of these alternatives contradicts the principle of the irreversibility of structural forms, as well as the laws of physics in general. The second has not been observed thus far in any of the thoroughly drilled areas of the platform. For this reason t must be believed that the uplifts of the II and III orders that arose in the sedimentary complex would, in the succeeding phases, have either increased in amplitude or (because of the appearance of new fractures in the crystalline basement) changed their shapes, complicating their original structures, or, finally, beome buried.

In its movements the series of sedimentary rocks is entirely dependent upon the behavior both of the individual basement blocks and of he crystalline basement as a whole. The vertically displaced blocks increase the surface of contact between the basement and the sedimentary rocks. For this reason in the formation of platform structures of the II and III orders in the sedimentary complex, only tensile stresses could arise, whereas compressive stresses have appeared only in the uppermost layers of the sedimentary complex and only in the tectonically downwarped areas corresponding to the contacts between two blocks whose surfaces are inclined toward each other, or else between two blocks one of whose surfaces is horizontal and the other inclined toward the first. In this case one may observe a slight coffering of the surface layers, gradually disappearing with depth.

The flexural steps of platform structures of the II and III orders in the vicinity of the crystalline basement must grade into faults. The depth of the transition of the flexural step and the fault is inversely proportional to the amplitude of the flexural fold. This transition between flexural steps into faults at depth has been determined by drilling on the Zhigulev flexural fold and has been described in a special article by K. B. Ashirov (1).

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STRATIGRAPHY OF THE MESOZOIC DEPOSITS OF THE VERKHNEZEYA TROUGH[1]

by

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This article proposes a new stratigraphic subdivision of the Upper Mesozoic deposits in the southwestern margin of the Verkhnezeya trough and determines their age on the basis of a spore-pollen analysis. The description of the section through the newly distinguished suites — the Verkhnezeya (J_3 - Cr_1), the volcanogenic suite, the extrusive complex of quartz —porphyries and the Zhurban suite (Cr_2) —includes a description of the rocks composing them.

* * * * *

There are Mesozoic deposits forming outcrops in the southwestern part of the Verkhnezeya trough, on the northern slopes of the Tukuringra Range, emerging from beneath the mantle of relatively flat-lying, friable Tertiary sediments along the banks of the Zeya River, between the villages of Zhurban and Inarogda.

The first information of the Jurassic age of these deposits was published in 1891 by V. A. Obruchev, who identified the plant remains collected by P. K. Yavorovskiy on the right bank of the Zeya River, near the mouth of the Gan River. According to P. K. Yavorovskiy [4], at the bottom of the section, directly overlying the gneisses, lies a thick (no less than 1000 m) series of boulder conglomerates; this changes upward in the section to sandstones, interlayering with argillaceous-arenaceous shales and rare thin interbeds of coals.

Much later [1] the Jurassic deposits of the Zeya River were described in greater detail by G. Ye. Bykov. According to him, the section through these deposits from bottom to top (in abbreviated form) contains the following:

1. Large-boulder conglomerates with interbeds of coarse-grained sandstone. In the upper part the amount of sandy material increases, and a tuff agglomerate appears in places. No less than 350 m (approximately).

2. Fine-gravel conglomerates, interlayering with sandstones containing some coal and traces of plant remains. About 150 m.

3. Greenish-gray and gray sandstones with interbeds of dark-gray shales containing traces of the same vegetation.

4. (Below the winter lodge of Filimoshka). Gray arkosic sandstones with interbeds of argillaceous and carbonaceous shales, coals and carbon resembling coal, with plant remains. More than 420 m.

G. Ye. Bykov called this series of Jurassic deposits the Zeya suite.

In 1939 L. G. Kotel'nikov gave a detailed description of the extrusive rocks within this suite. In his opinion [2, p. 160], "After the deposition of the Jurassic conglomerates, but before these rocks had been cemented (that is, in Jurassic times), there was an outflowing of andesitic lavas, so that in some places the Jurassic gravels were surrounded and cemented by the andesite".

In recent years, as a result of geologic surveys, the section through this series of Mesozoic deposits has been described in varying degrees of detail by V. I. Serpukhov (1945), N. F. Levykin (1945-1951) and others, but the stratigraphy of this thick series has up to the present time been very little studied.

The new material presented in this article on the stratigraphy of the Mesozoic deposits in the Verkhnezya trough was collected by M. S. Nagibina in 1948 and 1956 in geologic field studies on the northern slopes of the Tukuringra Range, in the Zeya River valley.

[1] Stratigrafiya mezozoyskikh otlozheniy Verkhnezeyskogo progiba.

Composition and Stratigraphic Section of the Mesozoic Deposits

According to their composition and stratigraphic position, the thick series of Mesozoic deposits on the southwestern margin of the Verkhnezeya trough may be divided into four complexes: 1) the Verkhnezeya suite of conglomerates and sand-shale rocks with interbeds of coal; 2) a volcanogenic suite of andesitic composition; 3) an extrusive complex of quartz-porphyries and their tuffs; 4) the Zhurban suite of sandstones, gravelites and shales with interbeds of lignite.

The structure of these suites may be readily observed in excellent cuts along the right and left banks of the Zeya River, at places between the villages of Zhurban and Inarogda, representing continuous outcops extending 5 - 10 km. The cliffs formed by the conglomerates along the right bank of the Zeya are as much as 80 – 100 m high.

I. The Verkhnezeya suite. This name is proposed for the lower part of the section through the Mesozoic deposits in the Verkhnezeya trough. This suite has two members: a lower subsuite of older conglomerates and an upper subsuite of sandstones and shales containing coal.

a) The base of the section through the Verkhnezeya suite is a subsuite of boulder conglomerates and fanglomerates some 1000 - 1100 m in thickness. The basal strata of this subsuite, as may be seen on the right slopes of the Zeya River valley, some 3 km above the village of Inarogda, lie upon the eroded surface of gneisses, amphibolites and granite gneisses of Archean or Early Proterozoic age, which are crumpled into folds that trend northwest and are cut through by numerous dikes of gabbro.

The normal stratigraphic contact between the Mesozoic deposits and the gneisses is here complicated by a system of faults which border the Verkhnezeya Mesozoic basin on the south and southwest.

The gravels and boulders in the conglomerates have a varied composition, representing both the different rocks of the gneissic complex that forms the northeastern slopes of the Tukuringra Range, and the rocks of Proterozoic and Paleozoic appearance that form the northeastern slopes of the Dzhagda Range, including the Ogoronskaya suite (C_1?). The clastic material in the boulder conglomerates and fanglomerates is poorly sorted. Along with enormous boulders come 1 — 1.5 m in diameter, there are much smaller pebbles 3 — 5 cm in diameter. The average size of the pebbles in the lower layers of the conglomerate series is from 10 - 25 cm; this gradually decreases upward in the section. The rounding of the clastic material is also diverse; one finds both well-rounded pebbles and boulders, and angular or subangular fragments and blocks.

The largest boulders and pebbles are composed of rocks of the gneissic complex: pinkish granite-gneisses, gneisses and amphibolites of varying composition, gabbros, pegmatites and other rocks. There are smaller amounts of comparatively well-rounded metamorphic schists, quartzites, limestones, jaspers, siliceous schists and fine-gravel conglomerates.

The boulders and pebbles of the conglomerate are cemented by a coarse-grained sandy material of arkosic composition with a considerable content of mica minerals and accessories—epidote, orthite, garnet, apatite, magnetite, sphene and others. Smaller quantities of hornblende, pyroxene and more rarely tourmaline are also present. The mineral grains and pebbles are densely cemented by an argillaceous-chloritic cement.

In places the conglomerate shows cataclasis and cleavage. In the cataclastic zones the cement of the conglomerate is observed to contain a large amount of newly formed green chlorite and epidote, and the conglomerates are cut through by veins of calcite and zeolite.

b) The upper subsuite merges gradually into the lower. At its base one may observe an alternation of layers of coarse-grained sandstones and fine-pebble conglomerates. The section through the upper subsuite from bottom to top contains the following:

1. Light gray and greenish-gray coarse-grained and medium-grained micaceous-arkosic sandstones with interbeds of conglomerates (1.5 - 2 m). 30 m.

2. Large-gravel conglomerate, cemented by coarse-grained sandstone. 15 m.

3. Light gray coarse-grained micaceous-arkosic sandstones. 50 m.

4. Large-gravel conglomerate. 8 m.

5. Large grained gray micaceous-arkosic sandstones with thin interbeds of dark gray siltstones. 15 m.

6. Frequently alternating gray fine-grained sandstones, thin-bedded siltstones and carbonaceous shales. The thickness of the interbeds varies from 1 mm to 50 cm. 50 m.

7. Coarse-grained gray micaceous-arkosic sandstones with lenses of gravelites and thin — 1 to 2 mm — interbeds of carbonaceous matter. The sandstones are cross-bedded. 5 m.

8. Interlayering of dark-gray thin-bedded tstones, black carbonaceous shales and edium-grained sandstones. The thickness of e interbeds varies from several milimeters 15 cm. The bedding planes of the gray silt-ones contain the carbonized fragments of ant stems and leaves. 10 m.

9. Gray coarse-grained sandstones with a oss-bedded texture. The sandstone contains inely dispersed carbonaceous matter. 8 - m.

10. Frequently alternating dark-gray silt-ones with a fine-bedded texture and medium-ained sandstones, black carbonaceous shales d coals. The individual interbeds do not ex-ed 15 cm in thickness.

11. Gray large-grained sandstones with in-rbeds (up to 10 cm) of dark-gray siltstones—sible thickness 15 m (gap in outcrop).

12. Alternation of gray sandstones and dark-ay siltstones (0.2 - 1.0 m) with black carbo-iceous shales (2 to 20 cm). The siltstones ntain numerous plant remains. 50 m.

13. Gray and greenish-gray medium-grained icaceous-arkosic sandstones interlayered with arse-grained sandstones (up to 1 m) and lenses fine-gravel conglomerates. About 200 m.

14. Interlayered greenish-gray coarse-ained and fine-grained sandstones, siltstones d clay shales, among which are interbeds of avelites (up to 30 cm). In the upper part of e section among the sandstones there are in-rbeds of conglomerate (from 0.5 - 20 m). isible thickness 100 to 120 m.

The total thickness of the upper subsuite andstones and shales) is 550 - 600 m; that of e entire Verkhnezeya suite is 1600 to 1700 m.

The clastic material composing both sub-uites of the Verkhnezeya suite, although ex-remely varied, is nevertheless distinguished y its constant composition throughout almost e entire section.

In the upper subsuite there is a predomi-ance of arkosic sandstones with a considerable dmixture of mica minerals, primarily biotite. he composition of the accessory minerals in e sandstones is the same as in the conglomer-tes of the lower subsuite.

In the upper parts of the section through the erkhnezeya suite, in the interbeds of coarse-rained micaceous-arkosic sandstones and ravelites, one observes a somewhat higher ontent of clastic grains of bright-green horn-lende. The sandstones and siltstones are emented by an argillaceous-choloritic material hich fills only the pores between the clastic grains. The fragments are poorly rounded and poorly sorted throughout almost the entire section of the suite.

All of the Verkhnezeya suite is characterized by the presence of clear signs of dynamic metamorphism, especially along the zones of cleavage and cataclasis and near the contact with the overlying suite of vulcanogenic rocks. These indications are seen in the deformations of the minerals, especially the micas, and the partial recrystallization of the dark-colored minerals and the cement. Many fragments of mica minerals (biotite) are frequently contorted and highly chloritized.

In places the sandstones and shales are intersected by veins of calcite and zeolites, and the cement of the sandstones contains small amounts of coarse-crystalline calcite. In the upper part of the section through the Verkhnezeya suite, near the contact with the volcanogenic suite, the interbeds of gravelites and conglomerates contain the most intensively recrystallized cement. Hydrothermal action and dynamic metamorphism resulted in the recrystallization of the biotite and hornblende, and the appearance in the cement of newly formed, tiny flakes of greenish biotite, epidote and chlorite. These interbeds of coarse-grained sedimentary rocks are macroscopically similar to the tuffaceous rocks with their dense green cement.[2]

The deposits of the Verkhnezeya suite form a enormous monocline whose beds dip northwestward at an angle of 40 - 45°, in places complicated by smaller gentle folds and step-like normal faults.

II. The volcanogenic suite lies stratigraphically above the Verkhnezeya suite. A direct contact between these suites has not been observed. In the valley of the Zeya River the contact between the vulcanogenic and the Verkhnezeya suites is tectonic. Here along the contact is a complex of younger extrusive rocks such as quartz-porphyries, felsites and their tuffs.

The strike of the suite of volcanogenic rocks is to the northwest, coinciding with the strike of the deposits in the Verkhnezeya suite; the volcanogenic rocks also have the same northeastward dip. At the base of this suite lie conglomerates consisting of well-rounded pebbles and boulders ranging in diameter up to 0.5 m (and, in the case of individual large boulders, to 1 m), gneisses, granite-gneisses, gabbros, pegmatites, pink granites and other rocks, cemented with andesite. The conglomerates are interlayered with thin flows of gray, dark gray and violet-gray andesites, tuffs, andesitic

[2]It is possible that such interbeds of coarse-grained recrystallized rocks in the Verkhnezeya suite have been taken by some previous investigators to be interbeds of tuffaceous rocks.

volcanic breccias and tuffaceous sandstones. The thickness of the conglomerates has been roughly determined as several hundred meters.

Higher up in the section the lava flows are interlayered with waxy-red and gray andesites and their volcanic breccias. Some of the andesite lava flows, along with fragments and volcanic bombs of andesite, also include individual pebbles and boulders up to 1 m in diameter of granite-gneisses, gneisses and amphibolites. The thickness of the individual flows of andesites varies, but in places is very small — from 0.3 - 0.5 m.

In the upper part of the section the flows of reddish-gray and pinkish-gray andesites are interlayered with conglomerates and tuff-conglomerates containing rounded pebbles and boulders, ranging in size from several millimeters to 0.5 m in diameter, leucocratic granites, red gneissic granites, granite-gneisses, gabbros, pegmatites and angular fragments of pinkish-gray and gray andesites cemented by lavas or tuffs of andesite.

The total thickness of the suite of volcanogenic rocks is no less than 1500 m.

The variously-colored flows of andesites in the volcanogenic suite are nevertheless very close in mineral composition. They may be subdivided into only two varities, connected by gradual transitions and varying in the composition of their phenocrysts of dark-colored minerals; andesites with phenocrysts of augite, and andesites with phenocrysts of augite and biotite. Both varities of andesite have a porphyritic structure.

A large part of the phenocrysts consist of idiomorphic crystals of andesine No. 35-40, frequently with a zonal structure. In places they have been resorbed by the groundmass of the rock. The content of dark-mineral phenocrysts is constant neither in quantity nor in composition. The degree of decrystallization of the andesites, the dimensions of the phenocrysts and their relationships to the groundmass are extremely varied. The augite and biotite phenocrysts are usually idiomorphic. In the majority of cases the flakes of biotite are partially or wholly opacitized.

The groundmass of the andesite consists of brown glass, which in places contains distinguishable microliths of plagioclase, tiny grains of dark minerals and ore minerals, and more rarely numerous large idiomorphic grains of magnetite. Its structure is glassy, and in individual flows hyalopilitic or pilotaxitic, and more rarely trachitic. In some places in the andesite flows one may readily see a flow structure and sometimes an amygdaloidal texture. The tiny amygdaloids are filled with bright-green chlorite, and some of the narrow cavities with zeolite.

Secondary alterations of the andesites are slight, usually taking the form of a partial replacement of the biotite by chlorite, and of a slight sericitization and chloritization of the andesine. In the reddish-colored andesite flows one may observe intensive iron-staining of the groundmass and opacitization of the biotite, and more rarely quartzification and, in some places, carbonatization. The volcanic breccias consist of angular fragments of various decrystallized andesites, cemented by yellowish-brown glass.

Peplolitic and agglomeratic tuffs are distinguishable among the andesites. The peplolitic tuffs are dense, gray and violet-gray rocks consisting of tiny angular fragments of andesite and augite crystals and opaciticized biotite, buried in a yellowish-brown glassy cement. The agglomeratic tuffs are formed of angular fragments of andesite of various magnitudes, cemented by a finer peplolitic material buried in a yellowish-brown glassy matter.

III. Extrusive complex of quartz porphyries and their tuffs. The dikes of quartz porphyries that intersect the series of conglomerates cemented with andesite cement, and also the quartz-porphyries forming independent flows along the Zeya River, were first described by L. G. Kotel'nikov [2].

According to the present writer's observations, in a large meander of the Zeya River, east of the mouth of the Ugan River, along a zone of tectonic contact between the Verkhnezeya suite and the suite of volcanogenic rocks, on the right bank and partly on the left bank of the Zeya River, there are outcrops of quartz-porphyries and their tuffs. The conglomerates with andesitic cement and the andesite volcanic breccias of the volcanogenic suite along the contact zone are intersected by dikes of light-colored quartz porphyries and felsites of various shapes.

Small dikes of quartz porphry, from 0.2 - 1.7 m in thickness, are located along the fissures formed by normal faults cutting through the conglomerates and the andesite volcanic breccias, trending almost exactly north-south and dipping eastward at an angle of 80 - 85°. The quartz-porphyry bodies of more complex shape also have larger sizes (up to 50 m in cross-section). Their shapes testify that the magma penetrated along the fissures that intersect the suite of volcanic rocks, and flowed outward along the surfaces separating the andesite flows from the conglomerates (Figure 1).

In places the quartz-porphyries contain fragments of andesites and tuffaceous sandstones from the volcanogenic series, as well as argillites and siltstones, sandstones, and more rarely baked coals from the Verkhnezeya suite and fragments of granites carried in from the

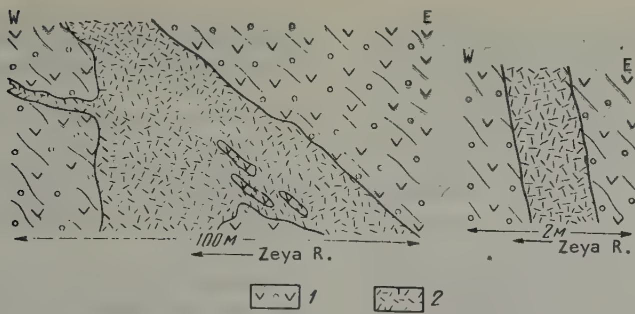

FIGURE 1. Sketch of the outcrops on the right bank of the Amur River above the mouth of the tributary Ugan River.

1 -- conglomerates and tuff conglomerates with andesitic cement; 2 -- quartz porphyries and felsites.

deeper strata. West of the contact between the conglomerates and the andesite volcanic breccias, on the right bank of the Zeya River and downstream, the quartz-porphyries form flows that are interlayered with tuffs of quartz porphyries. The thickness of the series of quartz-porphyry flows and their tuffs is here difficult to determine because of the absence of any continuous outcrops; in any case, it is no less than 250 m.

The quartz-porphyries composing the dikes have a porphyritic structure. The phenocrysts within them are idiomorphic crystals of completely transparent acidic plagioclase up to 1 mm in size, idiomorphic or fused grains of quartz and rare flakes of greenish-brown biotite.

The groundmass of the quartz-porphyries, which is either glassy or micro-crystalline, consists of tiny crystals of quartz, calcium felspar, albite and very small amounts of tiny flakes of biotite and an ore mineral.

Near the contact with the enclosing rocks the quartz-porphyries contain numerous fragments, showing various degrees of decrystallization, of quartz-porphyries, quartz grains and transparent felspar, as well as larger fragments of andesites, giving them the appearance of pyroclastic or brecciated rocks. In places the groundmass of the quartz-porphyries contains tiny amygdaloids filled with zeolites.

The flows of quartz-porphyries and felsites show clear flow structures. They also contain numerous fragments of various magnitudes — up to 15 cm in length, and more rarely greater — of sandstones and shales, and also baked coals from the Verkhnezeya suite, broken off during their intrusion. The quartz-porphyry tuffs interlayered with the flows of felsites and quartz-porphyries have various structures, represented by lithoclastic, agglomeratic and fine-grained peplitic varities. The latter form a dense, light-gray rock consisting of tiny splinters of quartz, transparent felspar and numerous peplitic particles of volcanic glass in the most varied (crescent-shaped, T-shaped) forms, fragments of pumice with a vesicular and fibrous structure, rare grains of epidote and occasional isolated large fragments of quartz-porphyries and andesites, as well as individual minerals out of the granites and gabbros from the ancient complex. The peplitic particles are embedded in a transparent glassy cement which is almost uncrystallized. The refractive index of the glass is lower than that of Canada balsam.

The agglomeratic and lithoclastic tuffs consist of large (from 1mm to 5 cm) fragments of quartz-porphyries, felsites, pumice, with rarer fragments of sandstones, granites and other rocks, as well as quartz and felspars cemented with a very fine peplitic material in a light glassy mass.

The quartz-porphyries and their tuffs show almost no traces of secondary alteration.

IV. The Zhurban suite. This is the name proposed for the uppermost part of the section through the Mesozoic deposits in the Verkhnezeya trough, the beds which lie stratigraphically above the suite of volcanogenic andesite rocks and the extrusive complex of quartz-porphyries.

The Zhurban suite is composed of interlayered sandstones, argillites and thin interbeds and lenses of gravelites, fine-pebble conglomerates and thin lenses and interbeds of lignites and carbonaceous coals. The rocks of this suite are poorly cemented with a carbonate and clay-like cement, and fall apart easily when struck with the hammer.

A good section through the Zhurban suite may be observed in the base of the high terrace on the left bank of the Zeya River, below the village of Zhurban, at the Filimoshka lodge. Here the rocks of the Zhurban suite almost "stand on their head", forming a monocline striking northwest, almost parallel to the equator, and dipping northeastward at an angle of 60 - 80°.

No direct contact between the Zhurban suite and the volcanogenic suite has been found, but the composition of the clastic material in the sandstones and conglomerates of the Zhurban suite, which contains a large number of pebbles and tiny angular fragments of andesites and their tuffs and of quartz-porphyries from the extrusive complex, leaves no doubt of their next higher stratigraphic position. The thickness of the Zhurban suite is no less than 1000 m.

The characteristics and composition of the Zhurban suite may best be seen in the section described by the present author in 1956, from outcrops in the left bank of the Zeya River, below the Filimoshka lodge.

The lower strata of the Zhurban suite are composed of fine-pebble conglomerate, interlayered with coarse-grained sandstones. Above these, the section (from bottom to top) consists of:

1. Gray coarse-grained arkosic and polymict sandstones with lenses of gravelites and thin interbeds of black lignite (up to 2 cm). 200 m.

2. Interlayered black carbonaceous siltstones and gray siltstones. 1. 8 m.

3. Interlayered cross-bedded, coarse-grained sandstones and carbonaceous siltstones. The thickness of the individual interbeds ranges from 10 to 30 cm. 2 m.

4. Coarse-grained, gray, cross-bedded sandstones and gravelites. The base of this stratum contains traces of erosion. 1. 2 m.

5. Thin interbeds of gray siltstones and carbonaceous siltstones. 1. 3 m.

6. Gray medium-grained sandstones. 0. 3 m (gap in the outcrop of 8 m).

7. Similar to bed 5. 1. 2 m.

8. Similar to bed 4. 0. 4 m.

9. Interlayered gray coarse-grained sandstones and carbonaceous siltstones with cross-bedding. 1. 35 m.

10. Coarse-grained gray sandstones with lenses of gravelites. In the lower part of the stratum are lenses of fine-gravel conglomerates up to 20 cm in thickness. The sizes of the pebbles in the conglomerates vary from 0. 2 - 2. 0 cm.

11. Similar to layer 3. 2. 7 m.

12. Coarse-grained gray sandstone with cross-bedded texture and fine interbeds of carbonaceous siltstones (thickness 10 cm). 2. 2 m.

13. Gray and yellowish-gray siltstones with cross-bedded texture and very fine interbeds of carbonaceous matter. 1. 1 m.

14. Coarse-grained sandstones with cross-bedding. 0. 5 m.

15. Gray fine-grained sandstones, thin-bedded (from 2 mm to 1 cm), solidly cemented. 0. 2 m.

16. Coarse-grained gray sandstones with lenses of gravelites and interbeds of fine-bedded siltstones (up to 30 cm) and rare lenses of black lignites (up to 1. 5 cm). 2. 6 m.

17. Interlayered fine-grained, cross-bedded sandstones and fine-bedded siltstones with carbonaceous shales (from 5 - 20 cm). 3. 3 m.

18. Thin interbeds of gray siltstones and black carbonaceous siltstones. 1. 8 m.

19. Coarse-grained light-gray sandstones with cross-bedding, lenses of gravelites and traces of rapid eddying currents. The sandstones contain narrow lenses of black lignite up to 40 cm in length. The upper part of the layer contains numerous carbonized plant remains. The base of the layer consists of gravelites and lies upon the somewhat eroded surface of layer 18. 2. 3 m.

20. Similar to layer 17. 3. 5 m.

21. Gray coarse-grained sandstones and gravelites, cross-bedded, with very fine interbeds and lenses enriched in carbonaceous matter. 1. 1 m.

22. Similar to layer 13. 0. 4 m.

23. Similar to layer 21. 0. 8 m.

24. Similar to layer 13. 0. 8 m.

25. Light gray coarse-grained sandstones and gravelites with cross-bedding, and rare lenses of lignite (up to 0. 5 cm). In the upper part of the layer are numerous carbonized plant remains and traces of tree trunks (up to 5 cm in cross-section). 1. 2 m.

26. Gray siltstones with rare interbeds of sandstones (up to 10 cm), very fine interbeds

(1 - 2 mm) of carbonaceous shales and lenses of black lignite (up to 3 cm in thickness and 30 - 40 cm in length). 0.7 m.

27. Gray coarse-grained sandstones with lenses of fine-grained gravelites and carbonaceous shales (up to 3 cm). 1.1 m.

28. Similar to layer 26. 0.5 m.

29. Similar to layer 27. 0.6 m.

30. Similar to layer 26. 1.6 m.

31. A large-grained and coarse-grained sandstone, poorly cemented, with very thin interbeds and lenses of coal. The lower part of the layer contains gravelites. 1 m.

32. Similar to layer 13. 1.2 m.

33. Similar to layer 15. 0.3 m.

The total thickness of this part of the section through the Zhurban suite is 240 - 250 m.

In the upper part of the section through the Zhurban suite, one may observe the same interlayering of coarse-grained sandstones, dark gray and greenish-gray argillites, among which are interbeds of carbonaceous argillites and lignites. The coal-bearing prospects of this suite were studied in 1933 by G. Ye. Bykov [1]. In the vicinity of the Filimoshka lodge he discovered up to 20 layers of coal-like rocks, of which only 8 layers had a thickness of more than 5 cm, the remainder not exceeding 15 - 30 cm, and only one of them reaching 50 cm in thickness.

In the composition of its clastic material and cementing substance, and also in the sizes of its fragments, the Zhurban suite differs sharply from the Verkhnezeya suite. In the Zhurban suite, along with the abundance of arkosic material, there are large amounts of fragments and pebbles from the rocks of the volcanogenic suite — gray and reddish-gray andesites and their tuffs, and light-colored porphyries and felsites from the extrusive complex, which are absent in the Verkhnezeya suite.

The conglomerates of the Zhurban suite are composed of fine gravel, in distinction to the coarse gravel and boulders in the Verkhnezeya suite. The cement of the sandstones and conglomerates in the Zhurban suite is carbonate, in places containing epidote and chalcedony, whereas that of the Verkhnezeya suite is argillaceous-chloritic and in places micaceous-chloritic. The Zhurban suite is considerably less metamorphosed and as a rule shows no indications of dynamic metamorphism, which are usually readily seen in the Verkhnezeya suite.

The fine-gravel conglomerates and gravelites in the Zhurban suite consist of well-rounded grains and angular fragments of various colored andesites, andesite tuffs and more rarely fragments and pebbles of quartz-porphyries, felsites, granites, quartzites and a large amount of poorly rounded arkosic material (grains of quartz and plagioclase, usually highly altered, peliticized and sericitized). Much more rarely there are fragments of epidote and hornblende, as well as biotite and an ore mineral. The pebbles in the conglomerates are no more than 5 cm in diameter, but usually less. In their mineral composition

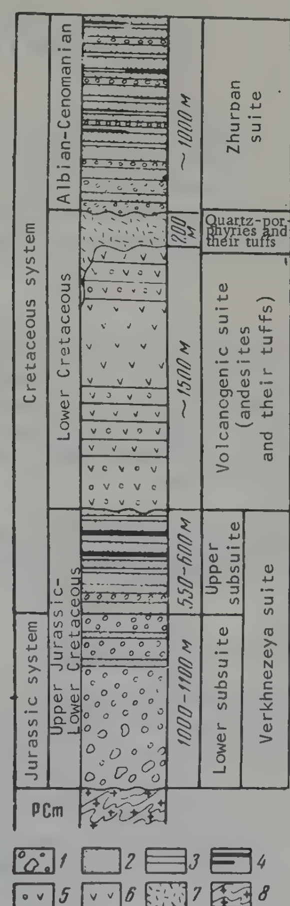

FIGURE 2. Stratigraphic column of the Jurassic and Cretaceous deposits in the Verkhnezeya trough.

1 -- conglomerates, fanglomerates and gravelites; 2 -- sandstones; 3 -- siltstones and argillites; 4 -- coal shales and lignites; 5 -- conglomerates and tuff conglomerates with andesitic cement; 6 -- andesites and their tuffs; 7 -- quartz porphyries, felsites and their tuffs; 8 -- Precambrian rocks.

and structure, the above-enumerated volcanogenic rocks in the pebbles of the conglomerate are completely like the andesite and andesite tuffs from the volcanogenic suite as described above, and the quartz-porphyries and felsites are not distinguishable from the rocks of the extrusive complex.

The gravelites and fine-gravel conglomerates are cemented primarily with secondary large-crystalline calcite, which not only fills the interstices between the fragments, but also penetrates the fissures in the pebbles and mineral fragments themselves. There is carbonatization even of the individual fragments of andesite, the phenocrysts of which have been replaced by the calcite. In places there is a calcite-epidote cement, and some of the most solidly cemented particular interbeds are held together with chalcedony.

The coarse-grained sandstones of the Zhurban suite merge gradually into the gravelites. They consist primarily of arkosic material — angular or poorly rounded grains of quartz, felspars and tiny fragments of andesites and their tuffs and quartz porphyries. The cement of the sandstones is the same as that of the conglomerates.

The medium-grained and fine-grained sandstones and siltstones, in addition to arkosic and volcanogenic material, contain considerable fragments of biotite flakes. The cement of these sandstones is also calcitic, but in places remains argillaceous and argillaceous-chloritic, with newly formed epidote.

The total thickness of the Mesozoic deposits in the southwestern part of the Verkhnezeya trough is about 4200 - 4400 m (Figure 2).

The Age of the Deposits

Various investigators, beginning in 1891, have considered this section of Mesozoic deposits in the Verkhnezeya trough to be Jurassic, on the basis of the plant remains contained in them. Not until 1945 - 1951 did N. F. Levykin, by correlating it with the sediments in the adjacent regions, subdivide the series of Mesozoic deposits in question into two parts: a lower one, consisting of sandstone, conglomerate and volcanogenic rocks, which he assigned to the Upper Jurassic and Lower Cretaceous, and an upper part of quartz-porphyries and their tuffs, which he called Lower Cretaceous.

Table 1 has been drawn up to correlate the various stratigraphic interpretations of the Mesozoic deposits in the Verkhnezeya trough suggested by different investigators.

In the upper subsuite of the Verkhnezeya suite, near the mouth of the Ugan River (the right tributary of the Zeya River), P. K. Yavorovskiy collected plant remains, among which V. A. Obruchev [3] has identified: Asplenium (Thyrsopteris and Dicksonia), Podozamites lanceolatus, Baiera (?) palmata, Ginkgo sibirica, G. lepida and Pityophyllum nordenskioldii.

Much later G. Ye. Bykov [1], in the same series of sandstones and shales, collected remains of plants, among which A. N. Krishtofovich has identified: Phoenicopsis angustifolia Hr., Pityophyllum nordenskioldii Nath. and Ginkgo lepida Hr. Later on, among the spores found by L. G. Kotel'nikov [2] in the same strata, V. D. Prinada identified the following flora: Phoenicopsis speciosa Hr., P. angustifolia Hr., Pityophyllum nordenskioldii Hr. and Ginkgo digitata Brong.; among the spores collected by V. I. Serpukhov (1945) he identified: Podozamites eichwaldii Schimp., Ginkgo sibirica Herr. and Sphenobaiera sp.

From the Zhurbanskaya suite G. Ye. Bykov [1] also collected plant remains, identified by A. N. Krishtofovich as: Ginkgo huttonii Hr. and Pityophyllum nordenskioldii Nath.

In 1956 the present writer collected twenty specimens of argillites and siltstones for spore-pollen analysis from the section through the Zhurbanskaya suite near the winter lodge at Fillimoshka. Thorough examination revealed that spores were contained in only five specimens; of these, N. A. Bolkhovitina has identified the following forms (see Table 2). Specimens 313, 317 and 321, from the middle of the section through the Zhurbanskaya suite, contained spores in abundance (some 100 to 200 grains in a single specimen). The spore content of these three specimens is similar, predominantly spores with smooth (ekzina), belonging to several species: Leiotriletes typicus Naum (4 - 38 %), L. gradatus (Mal. Bolch. (7 - 10%) and Hausmannia anonyma Bolch. (10 - 11%). Other species, Leiotriletes subtilis Bolch., L. perpusillus Bolch. and L. varius Bolch., were encountered in smaller quantity. Among other species, there is a constant occurrence of Adiantum glaber Bolch. (4 - 7%) and of a large number of pisolitic spores of the family Polypodiaceae, both small (3 - 17%) and large (3 - 24%). Spores belonging to the genus Anemia and to five species of Mohria are constantly present in all the specimens. In addition, the spores Gleichenia angulata Bolch., Woodsia reticulata Bolch., Dicksonia densa Bolch., Hymenozonotriletes bracteatus Bolch., Lophotriletes brevis Bolch., and Ophioglossum sp. have been found.

Pollen of Bennettites extensus Bolch., Gingko sp., and Caytonia oncodes (Harris) occurs as single grains. Pollen of conifers has been observed as rare grains (1 - 2% of the total), represented by Cupressacites intercisus Bolch., Pinys tricuspidata Bolch., P. insignis Bolch.,

TABLE 1

Comparison of Various Stratigraphic Schemes of the Mesozoic Deposits in the Verkhnezeya Trough

<table>
<tr><th colspan="2">P.K. Yavorovskiy, 1900</th><th colspan="3">G. Ye. Bykov[1], 1936</th><th colspan="3">L.G. Kotel'nikov, 1939</th><th colspan="2">V.I. Serpukhov, 1945</th><th colspan="2">N.F. Levykin, 1945 - 1951</th><th colspan="3">M.S. Nagibina. 1956</th></tr>
<tr><td rowspan="5">Jurassic</td><td rowspan="4">Sandstones and shales with interbedded fine-gravel conglomerates and coal measures with plant remains</td><td rowspan="5">Jurassic (J_2 - J_3)</td><td>4) Arkosic sandstones with interbedded shales and coal, more than 420 m</td><td rowspan="5">Zeya suite</td><td colspan="3"></td><td rowspan="5">Jurassic</td><td>Sandstone and shale suite, 1000 m</td><td colspan="2"></td><td>Cr_1^{alb} – Cr_2^{cm}</td><td colspan="2">Zhurban suite (sandstones, gravelites and argillites with interbedded lignites), 1000 m</td></tr>
<tr><td rowspan="3">3) Gray and greenish-gray sandstones and shales
2) Sandstones, shales and conglomerates. with interbedded coal. about 150 m</td><td>Quaternary</td><td colspan="2">Quartz porphyries and felsites</td><td></td><td>Cr_1</td><td>Quartz porphyries and their tuffs, 250 m</td><td rowspan="2">Cr_1</td><td colspan="2">Quartz porphyries and their tuffs, 200 m</td></tr>
<tr><td rowspan="3">Jurassic</td><td colspan="2" rowspan="2">Sandstones, shales and conglomerates</td><td rowspan="2">Volcanogenic-sedimentary suite, 1500 - 2000 m</td><td rowspan="3">Upper Jurassic/Lower Cretaceous</td><td>Andesites and their tuffs, 200 - 250 m</td><td colspan="2">Volcanogenic suite (conglomerates and andesites), 1500 m</td></tr>
<tr><td>Suite of sandstones and shales with interbedded conglomerates, 1500 m</td><td rowspan="2">J_3 – Cr_1</td><td>Upper subsuite (sandstone), 560 - 600 m</td><td rowspan="2">Verkhnezeya suite</td></tr>
<tr><td>Boulder conglomerate, 1000 m</td><td>1) Boulder conglomerate, 350 m</td><td>Conglomerates</td><td>Andesites and their tuffs and tuff conglomerates</td><td>Basal conglomerate, 1080 m</td><td>Basal conglomerate, 650 - 700 m</td><td>Lower subsuite (conglomerate), 1000 - 1100 m</td></tr>
</table>

[1]The author points out that the thicknesses cited by him are not exact.

TABLE 2

Results of Spore-Pollen Analysis of Siltstone and Argillite of the Zhurbanskaya Suite (in percent)

Shurbanskaya Suite				Spore names
sample 321 (200 pieces)	sample 317 (100 pieces)	sample 313 (100 pieces)	sample 306	
11		10		Hausmannia anonyma Bolch.
38	29	4	1	Leiotriletes typicus Naum.
4	1			" subtilis Bolch.
10	7	8		" gradatus (Mal.) Bolch.
	1	8		" perpusillus Bolch.
	5			" varius Bolch.
8	1	1		Divisisporites euskirchenensis Thomson.
1				Onychiopsis elongata (Geyler) Yocoyama
4	7	7		Adiantum glaber Bolch.
	1			Osmunda sp.
3	20	24		Polypodiaceae (large leguminous)
4.5	17	3		" (small leguminous)
		3		Anemia macrorhyza (Mal.) Bolch.
1		7	·	Mohria medicstriata Bolch.
5		4		" minutestriata Bolch.
1.5	6	1		" tersa K — M
1	1			" namziensis Bolch.
			1	" sp. (large spore)
1.5				Woodsia reticulata Bolch.
1				Gleichenia angulata Bolch.
		1		Selaginella vaginatiformis Bolch.
1	3	3		Dicksonia densa Bolch.
		1		Lophotriletes brevis Bolch.
	1			Hymenozonotriletes bracteatus Bolch.
	1	1		Ophioglossum sp.
		1		Lycopodium aff. undulatum L.
1		3	1	Unidentified spores
1.5		7		Cupressacites intercisus Bolch.
		1		Pinus tricuspidata Bolch.
		2		Protopicea accepta Bolch.
1				Pinus insignis Bolch.
0.5				Cedrus sp.
		1		Podocarpus paris Hlonova
		1		Picea sp.
1		2		Ginkgo sp.
1				Unidentified pollen
6		1		Bennettites extensus Bolch.
1.5				Angiospermae (Unidentified pollen)
				Caytonia oncodes Harris

Protopicea accepta Bolch., Podocarpus paris Hlonova, Picea sp. and Cedrus sp. Rare specimens of unidentified angiosperm pollen have also been encountered.

The species listed above were found and first described in the Khatyrykskaya suite (Albian) and in the lower part of the Timerdyakhskaya suite -- the Agrafenovskaya subsuite, which occurs along the middle reaches of the Vilyuy River and its left tributaries, the Tyungu and Linda Rivers, and also at the village of Namtsy on the Lena River, about 130 km from Yakutsk. On the basis of his study of leaf remains, V. A. Bakhrameyev has assigned the Agrafenovskaya suite to the Cenomanian/Turonian stages. Since all the species of spores and pollen found in specimens 306, 313, 317 and 321 occur in the Agrafenovskaya subsuite and the Khatyrykskaya suite, we may consider the Zhurbanskaya suite to belong to the top of the Lower and bottom of the Upper Cretaceous in age (Albian/Cenomanian).

The age of the Verkhnezeya suite, which underlies the series of volcanogenic rocks, is much harder to determine, inasmuch as the plant remains contained in the suite are not index fossils but are widespread throughout the

sediments of the Jurassic and Cretaceous systems. The pollen found in the specimens from this suite is almost unidentifiable, and only three spore grains have been encountered, of which two species also occur in the Zhurbanskaya suite (Mohria mediostriata Bolch. and Woodsia reticulata Bolch.).

In contrast to the spore-pollen composition of the Zhurban suite, here one finds a considerable amount of conifer pollen grains, which are so corroded that they are almost completely unidentifiable. Nevertheless some indications suggest that these grains are similar in type to certain species of the Early Cretaceous.[3]

The fresh water-continental (in the upper part, coal-bearing) deposits of the Verkhnezeya suite are similar in composition to the Upper Jurassic coal-bearing deposits and Lower Cretaceous deposits of the enormous Ud basin located northeast of the Verkhnezeya trough and separated from it by a small "cross-piece" of ancient crystalline rocks. Moreover the deposits of the Verkhnezeya suite are composed of sediments similar to the fresh water-continental series of the Amur and the Amur-Zeya River basins, especially the upper parts of the sections through these series. The age of the fresh water-continental and coal-bearing deposits in the basin of the upper reaches of the Amur River, according to their contents of plant remains and fresh-water fauna, has been determined as late Late Jurassic - Early Cretaceous.

On the basis of comparison with the adjacent regions, the deposits of the Verkhnezeya suite are also tentatively placed at the top of the Upper Jurassic - and Lower Cretaceous. This date is not contradicted by the plant remains contained in them.

The suite of volcanogenic rocks, according to its stratigraphic position between the Verkhnezeya ($J_3 - Cr_1$) and the Zhurban suites (Cr_{1-2} - Albian — Cenomanian) must be dated in the second half of the Early Cretaceous. This suite, represented by the conglomerates with andesitic cement, interlayered with andesite flows and their tuffs, is very close to the volcanogenic-sedimentary series that occurs farther to the northeast along the northern margin of the large Ud basin.

Conclusion

The formation of this series of Upper Jurassic and Cretaceous deposits occurred in the marginal parts of the large intermontane Verkhnezeya basin, under the conditions of a highly dissected relief. The formation of the boulder conglomerates and the fanglomerates composing the lower subsuite of the Verkhnezeya suite was due to the activity of rapid currents and mountain streams flowing down the slopes of the great Tukuringra-Dzhagda anticlinorium, composed of ancient Precambrian and Paleozoic deposits. The materials transported by the rivers and mountain streams were deposited in the foothills of these ranges, along the margin of the rapidly subsiding basin. Until the end of the deposition of the upper subsuite of the Verkhnezeya suite, there was a certain leveling of the relief, followed by a sharp decrease in the transportation of coarse clastic material, so that the proluvial facies disappear and are replaced by sandstone and shale deposits of the foothill alluvial plains, which in places were covered by marshes and standing water in which the thin interbeds and lenses containing carbonaceous material accumulated.

The tectonic movements at the end of the Jurassic and beginning of the Cretaceous periods caused the quite intensive folded dislocations of the thick (1600 - 1700 m) alluvial-proluvial series of the Verkhnezeya suite, which is complicated by numerous normal faults and thrusts. The greatest faults occurred along the southwestern margin of the Verkhnezeya trough. Intensive erosion of the rejuvenated mountain relief again caused an accumulation of thick boulder conglomerates.

The uninterrupted tectonic movements were accompanied by volcanic activity, and in places along the faults there were outpourings of lava flows of andesitic composition, which picked up loose gravels and cemented them. The flows of andesites were accompanied by the ejection of pyroclastic material. As a result of this intensive volcanic activity during the Cretaceous period, which occurred under continental conditions, as testified by the intensity of the opacitization of the biotite, a thick (up to 1500 m) series of volcanic-sedimentary rocks of andesitic composition was accumulated. Hydrothermal solutions associated with the volcanic activity percolated through the fissures in the coarse clastic and sandstone-shales deposits of the Verkhnezeya suite and considerably facilitated their metamorphism and the formation of the numerous tiny veinlets of calcite, epidote, chlorite and zeolites that intersect these deposits.

The dislocated volcanogenic-sedimentary formations of andesitic composition were cut by veins and dikes of quartz-porphyries and felsites. In places this acidic lava also poured out on the surface. These flows were accompanied by pyroclastic ejections that served as the source for the accumulations of agglomeratic and lithoclastic tuffs and very fine peplitic tuffs of quartz-porphyries that are interlayered with the lavas. The hypabyssal bodies of

[3]This conclusion, in the opinion of M.A. Bolkhovitina, must be reinforced by further analysis.

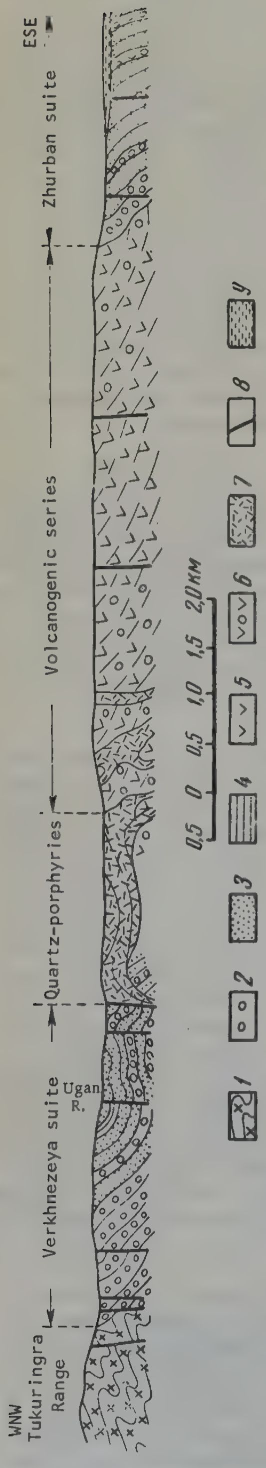

FIGURE 3. Geologic section through the southwestern margin of the Verkhnezeya trough.

1 -- gneisses, amphibolites and granite-gneisses (P - Cm); 2 -- conglomerates and fanglomerates; 3 -- sandstones and siltstones; 4 -- argillites, coal shales and coal; 5 -- andesites and their tuffs; 6 -- conglomerates and tuff conglomerates with andesitic cement; 7 -- quartz-porphyries, felsites and their tuffs; 8 -- normal faults; 9 -- sands and gravels (Kz).

quartz-porphyries here show traces of molybdenum mineralization.

At the end of the Early Cretaceous the Volcanic activity died out, and the continuing subsidence of the Verkhnezeya basin resulted in the accumulation of the thick (more than 1000 m) alluvial, somewhat carbonaceous deposits of the Zhurban suite (Albian-Cenomanian). The composition of the clastic material in the Zhurban suite indicates that during this time not only the adjacent mountain structures composed of ancient Paleozoic and pre-Paleozoic crystalline rocks, but also the young formations of the volcanogenic suite of andesitic and acidic composition, were subjected to erosion.

The deposits of the Zhurban suite were also dislocated, almost "stood on their head" and cut by normal faults of small amplitude (Figure 3). The cementation of these deposits is uneven and is associated with continuing hydrothermal activity, as indicated by the secondary cement consisting of large-crystalline calcite, epidote, chalcedony and chlorite. The Verkhnezeya trough continued to subside in the Late Cretaceous and the Tertiary period. The eroded surface of the dislocated deposits of the Zhurban suite, toward the center of the Verkhnezeya basin, is gradually buried beneath a series of unconsolidated sediments of the Tsagayan series, which overlies them almost horizontally or with a small angle of inclination.

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THE TRANSITION BETWEEN PARALIC AND LIMNIC FACIES IN THE UPPER SILESIAN COAL BASIN (CZECHOSLOVAKIA)[1,2]

by

Jan Petranek

The Upper Silesian coal basin, with an area of about 5600 km^2, is one of the most important coal areas of Europe. The greater part of it is located in the territory of the Polish People's Republic. Czechoslovakia contains only the southwestern part of this basin, forming the widely-known Ostrava-Karvina coal district.

The basin as a whole has the shape of a triangle, whose apex is located in the vicinity of Tarnovskiye Gory, and whose base leans against the Carpathian Mountains. In some places, at least, the geologic structure of the basin is continued beneath the Carpathians, as indicated by the results of drilling, and also by the presence of fragments and pebbles of coal in the Carpathian flysch and in the regions located at great distances eastward from the Upper Silesian basin. On the other hand, it is possible that these independent basins have similar developments and geologic positions.

Before turning to the problem of the transition between paralic and limnic sedimentation, let us take a quick look at the general geologic history of this region, including the time preceeding the deposition of the coal-bearing series.

The underlying beds crop out mainly in the western part of the Ostravo region. Among them one should first of all note various deposits of Devonian age, appearing some 40 - 100 km from Ostrava. In most cases these are various shales and limestones with traces of the appearance of very intensive igneous activity in the form of diabases, tuffs and tuffites (here some authors have called the Devonian deposits eugeosynclinal). Above lies a Lower Carboniferous series of flysch development with culm facies (some authors believe that these deposits are of the geosynclinal type). There are alternating beds of shales and graywackes.

The territory formed by the culm deposits is located between the main region of Devonian rocks in the west the Upper Carboniferous Ostrava-Karvina basin in the east. This position is the result of a gradual migration of the center of sedimentation toward the east (with a simultaneous uplift and partial erosion of the western part of the Devonian rocks). This general tendency clearly appears also in later times, when in the Late Carboniferous (Namurian-Westphalian) coal-bearing series were being deposited still farther to the east (without any noticeable interruption in sedimentation between the culm times and the Later Carboniferous). The beds of the molasse type, containing numerous coal seams, were deposited during this concluding phase.

From the standpoint of tectonics, the Upper Silesian basin may be regarded as one of a number of depressions in the geosynclinal region. The greatest tectonic dislocation is seen in its western part, whereas toward the center and the eastern margin the tectonic processes are more weakly manifested; there one even encounters gently folded brachyanticlinal and brachysynclinal structures.

The Namurian stage begins with barren beds, up to several hundred meters in thickness, consisting mainly of sandstones.

Above these are the paralic coal-bearing deposits, which have been designated as the Ostrava suite (from the city of Ostrava, where they are most easily accessible and most thoroughly studied). These deposits are completely contained within the Namurian stage, their thickness being approximately 3000 m. They contain numerous interbeds of clay rocks (argillites), partly calcareous, with marine or brackish-water fauna. Toward the north these marine strata are more clearly distinguished, and toward the south, parallel with the decreasing thickness of the beds,

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[1]Perekhod paralicheskikh fatsiy v limnicheskiye v Verkhnesilezskom utol'nom basseyne (Chekhoslovakiya).

[2]A paper on this subject was read by the author at Moscow in 1958, at a meeting of the Committee on the Distribution of Coal Deposits.

certain zones become fresh-water or grade into clearly brackish-water deposits. In the Ostrava beds numerous coal seams are encountered, but these are of comparatively small thickness.

Above lies the so-called Sedlovinnaya group of beds, which also belong to the Namurian stage; this is of small thickness, usually 200 to 250 m. The Sedlovinnaya beds, together with the succeeding beds above it in the Ostrava-Karvina basin, are exclusively limnic in nature (within Poland, in certain cases, some exceptional brackish water forms such as Lingula appear, etc.). The transition from paralic to limnic facies in the Ostrava-Karvina basin is observed mainly at the boundary between the Ostrava and Karvina suites — that is, between the Porubskaya and the Sedlovinnaya beds.

The Sedlovinnaya beds are characterized by variable thickness, which in the northeast (in Poland) decreases to nothing, and they wedge out, exactly as do the overlying beds corresponding to Westphalian A and the lowermost strata of Westphalian B. In the western part of the Upper Silesian basin one may observe a continuous series of beds, and here, above the beds of the Sedlovinnaya zone, appear typical limnic beds of Westphalian A, B, and C.

In the uppermost layers of the Westphalian the greatest sedimentary accumulation is observed still farther northward in the basin. Here were deposited the beds of Westphalian D, characterized by a comparatively small degree of compaction and a quiet medium of deposition; the coal that terminates them is transitional to brown coal. Deposits of the Stephanian stage and the Permain are also known in approximately the same area (Poland). The Stephanian stage is here represented by arkoses, and the Permian system by coarse-grained conglomerates which are red in color, by melaphyric tuffs and extrusives.

The total thickness of the coal-bearing beds of the Carboniferous in the west is about 6900 m, and in the east 2700 m.

As already mentioned, the boundary between the paralic and limnic deposits occurs as early as the middle of the Namurian stage, and coincides chiefly with the boundary between the Ostrava suite and the beds of the Sedlovinnaya group. This boundary is not a sharp one; indications of a transition to limnic deposits appear in the uppermost Ostrava beds. Here, for example, is the Yaklovets group of beds (thickness about 350 m.), which contains almost exclusively fresh-water fauna. Thereafter was deposited the more than 800 m. Porubskaya group of beds, in which occur marine strata at a small distance below the limnic Sedlovinnaya group of beds.

The differences in facies between the paralic and limnic deposits is readily seen. The paralic parts of the section consist mainly of an alternation of deposits of transitional facies with alluvial and swamp deposits. Typical marine deposits are not encountered so frequently. In the Sedlovinnaya beds, forming the base of the limnic series, there is a predominance of alluvial deposits; these are not only sand and silt sediments, but also a large amount of sandy channel deposits and conglomerates. In the overlying parts of the section there is a decrease in the amount of the coarsest channel deposits and an increase in the number of floodplain and swamp facies. the general features of these facies differences are also reflected in the predominant types of bedding. Whereas in the limnic series one frequently encounters clear, coarse cross-bedding, in the paralic deposits one most frequently finds horizontal and complex bedding, formed by alternating layers of different granulometric and petrographic composition. Here there is frequently a regular and uniform alternation of beds, recalling lenticular bedding.

The structures of both complexes also differ strikingly in their basic features. In the paralic series, even when there is considerable variation in the lithologic composition, one generally observes more stable conditions of sedimentation. On the other hand, in the limnic series, even directly at its base, both the coal seams and the enclosing rocks are less stably developed. One frequently observes various eroded areas in the coal seams, as well as rapid branching and joining of the seams, etc. The classic example of such development is the well known Sedlovinnaya group in the northern part of the Upper Silesian basin, 270 m. in thickness, containing 6 industrial coal seams. Toward the east this group gradually becomes thinner, the coal seams unite, and at a distance of 32 km. the entire Sedlovinnaya group is represented by a single 12-meter coal seam and a 3-meter layer of overlying sandstones. The coal seam in places reaches a thickness of 24 m, filling up the entire Sedlovinnaya group, which in other places wedges out entirely.

Indications of similar lithologic structure are also observed in the southwestern part of the basin, where one of the main anticlinal structures—the Orlovskaya fold—is developed. Here one may see not only a decrease in the thickness and the number of certain seams and of the entire group, but also some manifestation of hypabyssal and extrusive igneous activity, resembling the melaphyric in type.

Direct manifestations of igneous activity are not known in the paralic series. Moreover, in the lower part of the Ostrava beds one encounters rocks (a stratum of whetstones

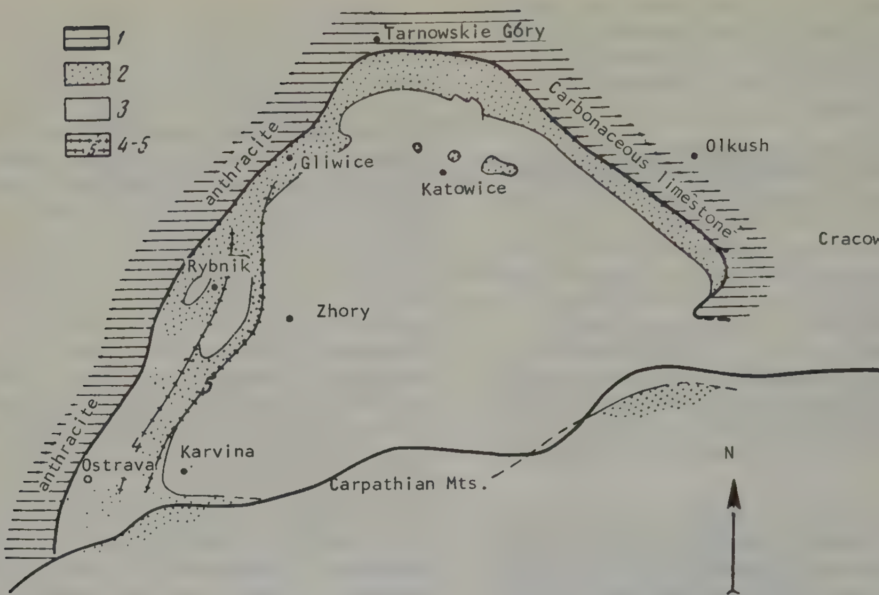

FIGURE 1. The Upper Silesian basin (after various authors):

1 - underlying non-producing series (anthracite or bituminous facies); 2 - so-called littoral paralic complex (Ostrava beds in the Czechoslovakian part of the basin); 3 - so-called Central Basin complex, essentially limnic (Karvina beds in the Czechoslovakian part of the basin); 4 - Mikhal'kovitskaya fold; 5 - Orlovskaya fold, grading northward into a normal fault.

and pseudowhetstone rocks), in which, according to many authors, there is quite a large amount of tuffaceous materials. The renewal of volcanic activity during the period of limnic sedimentation is in all probability genetically associated with general tectonic factors determining the transition from the paralic sedimentation to limnic.

It is also important to note the presence of varicolored rocks in the limnic series, whereas in the paralic series they are almost never encountered. The formation of these rocks may be explained not only by conditions of dry plains, but also by the transport into the area of sedimentation of red-colored weathering products. Here there must have been a decomposition of mainly volcanic rocks, particularly the lavas or pyroclastic material that is encountered principally in the area of the Orlovskaya fold, one of the main anticlinal zones of the Upper Silesian basin. The origin of this fold is partly simultaneous with the sedimentation, since its uplift began within the period of deposition. Along this fold were the main occurrences of Carboniferous volcanic activity, and in its vicinity the varicolored beds are most widely developed.

In the paralic series the coal seams in most cases reach thicknesses of about 1 m, but are frequently even less. In the limnic series, on the other hand, thicker seams are encountered; in the vicinity of Ostrava cases are known in which the seams in the Sedlovinnaya group merge together, reaching a total thickness of 12 m. (another similar case was noted above). In the limnic series the coal beds are also located close to each other, so that the coal content of this series is much greater than that of the paralic series. For example, in the Lower Ostrava beds the coal content is 1.5 - 2 %, and in the Upper Ostrava beds 1.8 - 2.2 %, whereas in the limnic beds of the Sedlovinnaya zone it is 6 - 12 %, in the Sushskiye zone 8 - 9 % and the Doubravskiye zone 4.5 %.

Similar differences are also observed in the thicknesses of the cycles. Individual cycles in the limnic facies are greater in the vertical direction than in the paralic facies.

The limnic series contains more numerous argillaceous-carbonate concretions than does the paralic series, and here one frequently encounters vertical trunks and stems of trees, particularly in the overlying rocks of the coal seams. In the paralic series, on the other

hand, trunks and stems are rare. Well-preserved plant remains are also more numerous in the limnic than in the paralic beds, since fine plant detritus is for the most part encountered in deposits of lagoons and bays and even in typical marine basins. Fauna is, of course, also more frequently encountered in paralic media.

As regards the petrography of the deposits under consideration, it is important to note the presence of arkosic rocks in the limnic facies, as well as the fact that they are less thoroughly compacted. In sandstones of limnic origin there is a large amount of almandite garnet, the serrated and non-rounded forms of which some investigators explain as signs of authigenic origin.

Along with the transition from paralic sedimentation to limnic, there are also some changes in the composition of the coal. According to K. Benes and M. Dopita (1), vitrains and clarains are encountered mainly in the lower beds; in the higher Ostrava beds and also in the Karvina beds one most frequently sees series of clarain-durain. In the younger series fusains are most frequently found in the composition of the coal.

The content of sulfur in the coal (3) also differs. The coal seams of the limnic series (group of beds) generally contained more sulfur (up to 3%) than the paralic, where wht amount of sulfur is usually no more than 1.5%, and frequently not more than 0.5%.

In conclusion, let us consider the amount and chemical composition of the coal ash in the seams. The coal seams of the paralic complex generally have less ash than those of the limnic; this is due to the presence of frequent interbeds in the seams of the limnic series.

A study of the chemical composition of the coal ashes in the paralic and limnic series, in strata with a total thickness of about 4000 m, revealed certain regular changes. The results of analyses of the ash showed that from the older to the younger series—that is, from paralic to limnic—there is an increase in the content of Al_2O_3 and SiO_2, and decreased amounts of Fe_2O_3, CaO and MgO. In both cases, of course, there are clear deviations in the diagrams of these oxides, especially in the transitions from paralic sedimentation to limnic—that is, in the Porubskiye and Sedlovinniye beds (for example, an increased content of Fe_2O_3). The difference in the composition of the ash may generally be expressed by the magnitude Q (Teune), which in the paralic series (on the basis of 105 analyses) amounts to 3.15%, and in the limnic series to 5.10% (75 analyses).

From the practical standpoint, this means

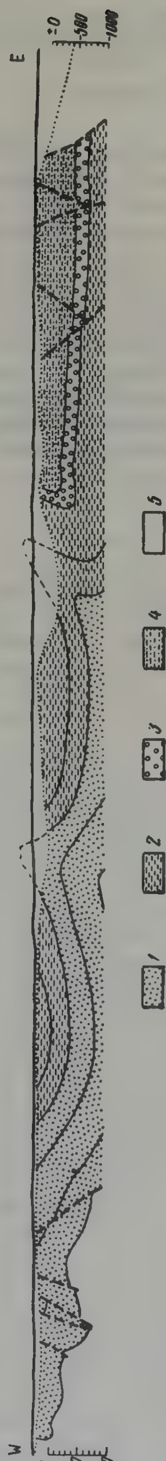

FIGURE 2. East-west section through the Ostrava-Karvina basin (with corrections, based on Sendler, Rusk, Drastikh, Vengrshin and Vitask).

From left to right: the Ostrava basin, the Mikhal'kovitskaya fold, the Petrshval'dskiy basin, the Orlovskaya fold and the Karvina basin; 1 - Lower Ostravskiy beds, 2 - Upper Ostravskiy beds, 3 - Sedlovinnaya group, 4 - Sushskiye and pre-Ubravskiye beds, 5 - Neogene.

a higher melting point of the coal ash in the stratigraphically higher strata, so that in the limnic series the composition of ash in certain seams suggests that such seams may be useful in the production of aluminum.

* * *

The examples cited above indicate the multitude of geologic conditions association with the transition from paralic facies to limnic. Detailed determination and explanation of all the genetic associations and causes of such phenomena will require further investigation. Nevertheless the data cited here, in the author's opinion, show that a study of the facies conditions of deposition in coal-bearing series may aid in discovering the causes of the development and genesis of coal seams, as well as of the accompanying rocks and the entire sedimentary series as a whole.

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PHOSPHATIZED BAUXITE CONCRETIONS IN THE LOWER JURASSIC COAL SEAM IN THE VICINITY OF KARPINSK IN THE NORTHERN URALS

by

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In 1956, in the Veselov brown-coal deposit, were found spherical formations that turned out to be phosphatized bauxites. This deposit is located on the eastern slopes of the Northern Urals, some 8 km southwest of Karpinsk, in a tectonic depression within Devonian rocks that is filled with Upper Triassic and Lower Jurassic deposits.

The Devonian is represented by limestones, clay shales and felspar sandstones, which may be partly tuffaceous. Somewhat to the west of the Veselov deposit there are Silurian formations, among which are many basic rocks.

Upon the eroded surface of the folded Devonian rocks lies a series of Mesozoic sediments. This has been subdivided by Ye. V. Shapiro and Yu. P. Ovchinnikov into four layers (from bottom to top): 1) a varicolored layer, 2) a sand and conglomerate layer, 3) a coal layer and 4) a super-coal layer. The varicolored layer is composed predominatly of red clays, which in places are brecciated. The sand-conglomerate or sub-coal layer is composed of sandstones and conglomerates, the coal layer of argillites, siltstones and coals, and the super-coal layer of sandstones, argillites and siltstones.

The bauxite is encountered only in the third coal seam. This is the lowermost working seam of the coal layer (Figure 1). The thickness of this seam ranges from 1.5 - 6.0 m. It is usually underlain by gray argillites and more rarely by different varicolored rocks. It contains up to 12 thin discontinuous interbeds of argillite and concretions of siderite, ankerite and bauxite.

The bauxite concretions are spherical or ellipsoidal in shape; the long axis of the ellipse is horizontal—that is, parallel to the bedding. The concretions are usually 0.2 - 0.4 m, and sometimes 0.3 - 0.5 m, in size. They are not hard, but are readily broken with the hammer into pieces showing conchoidal fracture. Small seams of coal surround the concretions. The boundary between the concretions and the coal is distinct, but not sharp, going through a transitional zone 2 - 5 mm in thickness.

Two types of bauxite concretions—pisolitic and aphanitic—have been distinguished.

The pisolitic concretions are composed of spherical pisolites and cement (Figure 2). The diameter of the pisolites varies from 2 - 5 mm, and their color is pinkish-gray to red-brown. The cement is gray or dark gray, in places with a pink tinge. Along with the pisolites, the concretions contain pebbles of fine pisolitic bauxite, up to 6 mm in diameter, and fragments of mineralized wood.

In thin sections it can be seen that the cement is not homogeneous, but contains scattered tiny grains of the same substance as the pisolites. The size of these grains is 0.2 - 0.10 mm. The pisolites are homogeneous and oolitic. The material of the homogeneous pisolites is usually shot through with tiny fractures or veinlets, partly filled with a brown mass. These veinlets are predominatly radial and concentric. In shape, size and fracturing such pisolites are identical with the pisolites that are widespread in Mesozoic and Cenozoic bauxites. The oolitic pisolites consits of a quite large homogeneous core and from one to five not readily distinguishable concentric layers (Figure 3).

Figure 4 shows three pisolites and the edge of a rounded pebble of fine pisolitic bauxite. Its roundedness is shown by the inclusion within it, at its edge, of a hemispherical grain, the outer half of which has been worn away during the rounding. Such a pebble of bauxite with hemispherical grains at its edge may be seen also in Figure 2 (upper left). In the middle of Figure 4 there is a gray semi-transparent pisolite with slightly distinguishable concentric shells. At the upper edge of the pisolite these layers

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[1]Konkretsii fosfatizirovannogo boksita iz nizhneyurskogo ugol'nogo plasta v okrestnostyakh g. Karpinska na severnom urale.

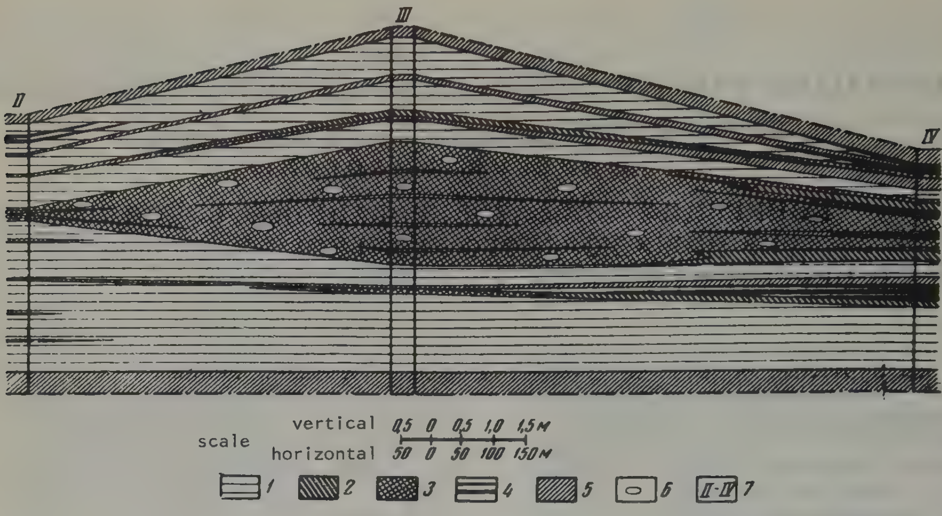

FIGURE 1. Structure of the third coal seam with bauxite concretions.

Sketch of open-pit mine in the southern part of the Veselov deposit: 1 - semi-glistening clarain coal with admixture of gelified substance, 2 - semi-dull clarodurain coal with semi-transparent and opaque substance, 3 - dull durain coal with semi-transparent and opaque substance, 4 - semi-dull clarain ash coal, 5 - argillite, 6 - concretions of phosphatized bauxite, 7 - bore holes in parts II, III and IV of open-pit mine.

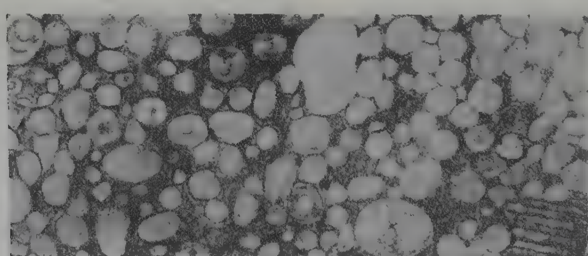

FIGURE 2. Pisolitic bauxite with cellulose fragments, polished surface of ore lump. Pebble of fine-pisolitic bauxite visible at upper left. Magnification x 2.

wedge out; they may have been worn away during its rounding. Within the pisolite are included four bauxite grains. The other pisolite is broken up by wedge-shaped fractures and almost completely destroyed. This fracturing of the pisolite apparently took place in situ, since the individual fragments are not displaced, and the interstices between them are filled with matter of the ground mass. The third pisolite, which is dark red, is highly ferruginous (black shape at right of Figure 4), and also shows traces of intensive fracturing in situ. Part of it has apparently been dissolved, and the products of its solution have been removed. The possible removal of iron from the sediment during the process of diagenesis has been considered earlier (1). Indications of destruction of the other pisolites, by resorption and leaching or removal of the iron, are readily seen, since the pisolites merge into the ground mass.

In thin sections one often sees pebbles of fine-pisolitic bauxite, fragments of pisolites and a large amount of phosphatized plant remains, with their cellular structure well preserved.

The plant remains are represented both by disconnected fragments of bark tissue or wood,

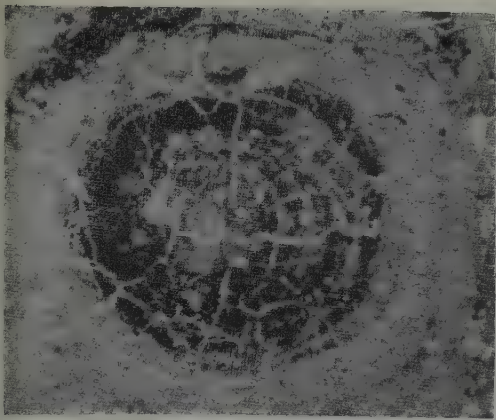

FIGURE 3. Pisolitic concretion with faintly marked oolitic structure, leached at the outer margins and partially fractured.

Transparent thin section, magnification x 20, without analyzer.

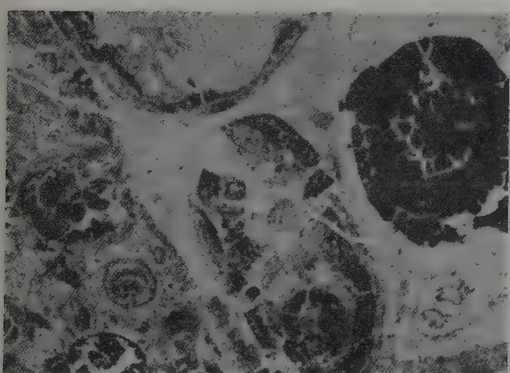

FIGURE 4. Pisolitic bauxite.

Three pisolites and the edge of a pebble of fine-pisolitic bauxite (left) are visible. Transparent thin section, magnification x 20, without analyzer.

and by whole stems and roots, which are round in cross-sections. According to their nature and the degree of transformation of the substance, the plant remains may be divided into three groups: 1) mineralized, 2) slightly gelified and 3) fusainized.

The mineralized plant remains are dark in color, and all the features of the cellular structure of their tissues are almost completely preserved. Such remains are characterized by the penetration of the cell walls and filling of the cell vacuoles by mineral substance - calcium aluminium phosphate or siderite.

The slightly gelified plant remains are colored brown. They have somewhat swollen, thickened cell walls and readily discernible cellular structure. In some tissues, because of their slight decomposition, one may see the tracheids—the conducting capillaries of the roots. It is interesting that highly gelified plant tissues—those in the vitrain or homogeneous ground mass stage—are not found in the pisolitic concretions.

The fusainized plant remains are distinguished by their black color. They are represented mainly by the products of mechanical attrition of larger gragments. The amount of substance resulting from this attrition is especially high in the parts of the concretions that border on the coal. Large fusainized fragments are rarely encountered. The cell vacuoles in both the fusainized and slightly gelified tissues are filled with calcium aluminium phosphate or siderite.

The aphanitic concretions are similar to the pisolitic in shape and size; their color is dark gray, in places with a greenish tinge, and they have a small specific weight because of their microporosity. In the mass of bauxite there are rare scattered gray and light-gray, loose, porous grains 1 - 2 mm in diameter. With a hand lens one may see even smaller light-gray grains 0.2 - 0.4 mm in diameter. Pinkish-gray pisolites are very rarely encountered in the concretions. The outer part of the concretions, some 4 - 5 mm in thickness, is lighter in color than the inner, because of its abundance of tiny light-colored dots.

In thin sections the material of the concretions is non-homogeneous, consisting of easily distinguishable grains and cement of an amorphous mass (Figure 5). The grains are 0.03 - 0.10 mm in diameter, and rarely larger. The boundary between the grains and the cement is not sharp, and in places dissappears completely. In transmitted light the grains are usually dark, and in reflected light they are lighter than the cement. In some grains one may observe a slightly visible concentric structure. Aggregates of microscopic siderite grains, quartz grains 0.02 - 0.05 mm in size, and vermiculites of kaolinite are sometimes encountered. Occasionally one may see tiny prismatic crystals of gibbsite, growing on the walls of the pores. Plant remains in the mass of bauxite are very few. Their tissues are either highly gelified with swollen cell walls and filled cell vacuoles, or else represented by fusain in the form of fairly large inclusions or tiny fusain material resulting from attrition.

Identification of the mineral nature of the substance in the concretions encounters serious difficulties because of its amorphous nature and the admixture of impurities. The pisolitic and aphanitic concretions resemble each other

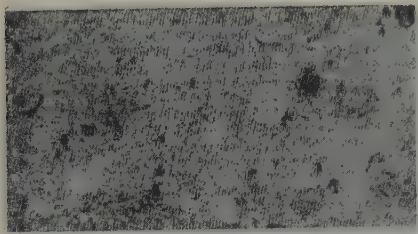

FIGURE 5. Aphanitic bauxite with fine bauxite grains, containing black carbonaceous remains. Transparent thin section, magnification x 20, without analyzer.

in chemical composition (Table 1). The latter are distinguished by a higher content of silicate admixtures and carbon. There is a noticeably high content of phosphorus and calcium, and a small amount of iron, which is unusual for bauxite. The refractive index of the material in the pisolites, the grains and the cement varies around 1.62—close to that of pseudowavellite. Some parts have a refractive index of 1.56 - 1.57, close to calcium aluminium phosphate—overite.

Standard thermograms for these phosphates are unknown, and the thermograms obtained by D. A. Vital in the laboratory of the Institute of Geology of the Academy of Sciences of the U.S.S.R. for the material of the concretions were not characteristic, apart from the peaks indicating the presence of gibbsite and kaolinite.

The X-ray powder photographs obtained by R. P. Ozerov in the laboratory of the Scientific-Research Institute of Fertilizers are similar for the pisolitic and aphanitic concretions. The lines are slightly diffused, and the strongest of them are 2.918, 2.150 and 143—characteristic of the pseudowavellite studied earlier by D. McConnell, (2). Moreover there are a number of lines close to those for pseudowavellite - 3.56, 2.94, 2.34 and 1.73. In spite of the high content of P_2O_5 and CaO, the X-ray photographs show no lines for apatite.

All these data suggest the conclusion that the concretions are composed of calcium aluminum phosphate, close to pseudowavellite —$CaAl_3(PO_4)_3(OH)_5$. H_2O—with admixtures of kaolinite, gibbsite, quartz, siderite and, apparently, overite—$Ca_3Al_8(PO_4)_8$. $(OH)_6$. $15H_2O$. Among the titanium minerals there is ilmenite. Pieces of the concretions upon heating become brittle and decrepitate, their gray color changes to white with a pinkish tinge and red spots, and the aphanitic concretions are whiter than the pisolitic, indicating a lower content of iron in the former.

Concretions of phosphitized bauxite are encountered in areas II, III and IV of the open-pit mines. These areas are located in the central and southern parts of the deposit. The coal seam is here composed of coals of four genetic types: 1) semi-glistening clarain, with mixed gelified substance; 2) semi-dull clarain ash; 3) semi-dull clarain-durain, with semi-transparent and opaque substance and 4) dull durain with semi-transparent and opaque substance. The phosphatized bauxites are included in a layer of durain coal (see Figure 1), whose properties we shall dwell upon briefly below.

The dull durain coal with semi-transparent and opaque substance has a black color with a grayish-brown tinge. Its structure is homogeneous, but streaked in places because of the presence of very fine streaks of glistening

Table 1

Chemical Composition of Aluminophosphate Concretions

Components	Pisolitic		Aphanitic		
	1	2	3	4	5
SiO_2	5.49	5.40	27.36	8.12	8.45
TiO_2	0.23	1.34	1.36	1.04	1.07
Al_2O_3	32.72	30.06	30.19	24.60	23.79
Fe_2O_3	0.08	4.58	1.62	0.93	0.05
FeO	3.34	not det.	not det.	not det.	2.44
CaO	9.32	9.10	4.26	9.72	8.47
MgO	0.13	0.44	0.62	0.43	0.11
P_2O_5	16.26	17.40	5.83	15.27	14.00
CO_2	1.56	1.68	0.24	1.16	1.72
H_2O^-	7.87	7.08	5.28	9.66	14.44
H_2O^+	10.30	11.12	9.72	10.32	11.39
C	5.63	5.74	6.51	10.20	8.04
Total	92.93	93.94	92.99	91.45	93.97

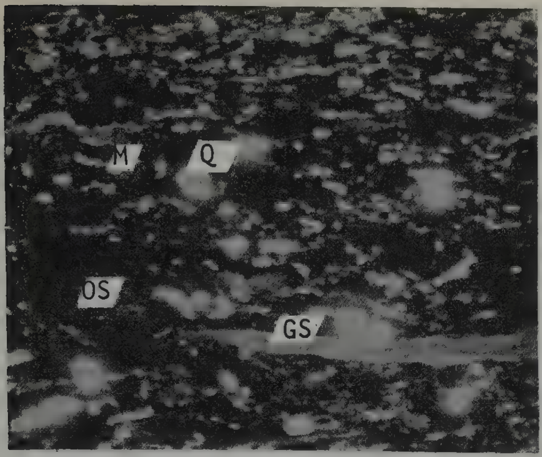

FIGURE 6. Durain with semi-transparent and opaque substance: OS - opaque and semi-transparent substance, GS - gelified substance, M - microspores, Q - quartz. Transparent thin section, magnification x 150, without analyzer.

vitrain and smaller or larger lenses of fusain. The coal layer contains many small lenses of argillite 1 x 0.5 and 2 x 5 cm in size, and also argillite layers that wedge out after a short distance. The coal has an angular fracture.

A characteristic feature of the microstructure of the coal is the sharp predominance of opaque and semi-transparent substance (75 - 80%), represented by the groundmass and the fragments of plant tissue (Figure 6). At a magnification of 300 to 500 it can be seen that the opaque ground mass consists of compact structureless pieces with fused and uneven contours. In a number of cases the pieces are translucent around their edges and show a brownish color. Fragments of tissue are present in the coal in altered state and form a vitrain-fusain attrital material. The fragments are of varied shapes, but usually lenticular or angular, often with fused contours, indicating a considerable degree of softening and liquefaction of the substance in the decomposition of the plant material.

Along with the opaque black fragments of organic matter, there are quite a few semi-transparent pieces of brown color. The gelified substance in the coal is represented by a small amount of homogeneous groundmass, distributed among the fragments as tiny red-orange spots and thin veinlets. Sometimes one may observe large lenses of red-orange vitrain.

Among the stable formed elements in the coal are microspores, macrospores, cuticles, bark tissue and bits of resin. The stable formed elements amount to 12 - 15% of the whole. The ash content of the coal is 19%, and contains grains of quartz, flakes of mica, argillaceous substance in the form of tiny lenses and siderite concretions. The extraction of humic acids from the coal was 65.2%.

The abundance in the mixed durain of semi-transparent and opaque groundmass and vitrain-fusain attritus, the small amount of gelified substance, the abundance of mineral admixtures and the large extract of humic acids suggest that the coal was formed under the conditions of a swamp with fresh water flowing into it, in which the reducing medium, as a result of the great inflow of water, could change upon occasion to more or less oxodizing medium, depending on the degree of saturation of the swamp water with oxygen-bearing air because of its movement.

The spherical formations of calcium aluminium phosphate in the coals have never before been indicated. The origin of these formations is a matter of great interest. The fact that these round formations are surrounded by layers of coal indicates that they were already solidified in the peat stage of coal formation. The absence in them of any traces of rounding, and the indistinct boundaries between them and the coal, suggests that they arose in situ—that is, as concretions. The shapes and sizes of the pisolites and the nature of their fractures (see Figures 3 and 4) indicate that they were formerly bauxite. The pisolites were apparently phosphatized at the same time as the phosphatization of the cement and the wood—that is, in the peat.

The presence of bauxite pebbles in these concretions, and the occurrence of the latter in the durain coal together with opaque and semi-transparent substance, corresponds to the conditions of a swamp with flowing water. To judge by the sizes of the pebbles, which reach 12 mm in diameter, the currents of moving water at times were quite rapid. These currents, together with the pebbles, may have transported the pisolites and smaller grains of bauxite. The existence of water currents in the swamp is also indicated by the presence of layers of argillite and sandstone in the coal. The presence in the bauxite pisolites of a large amount of plant remains with well preserved cellular structure indicates that the concretions were formed in the very earliest period of peat accumulation, when the plant material had scarcely begun to be decomposed.

The aphanitic concretions are typically composed of very tiny grains of calcium-aluminium phosphate and contain plant tissues with highly gelified cell walls and filled cell vacuoles. Hence these concretions must have been formed in the more stagnant parts of the swamp and, perhaps, in a later stage of diagenesis than the pisolitic concretions.

The traces of decomposition, which are especially clear at the periphery of the concretions, and also the absence of bauxite pebbles in the surrounding coal, point to the somewhat unexpected conclusion that beds or layers of bauxite were deposited in the swamp with flowing water. These layers or lenses were almost entirely destroyed in the process of diagenesis, so that only small fragments of them were preserved, cemented as concretions. Hence the enormous importance of diagenesis in the formation of sedimentary bauxites becomes clear, but this process requires farther study in other deposits.

The high percentage of phosphate in the concretions suggests a possible high content of this substance in the rocks of the area that was the source of sediments; these rocks may even have contained phosphorites. The occurrence of pebbles of fine-pisolitic phosphatized bauxite indicates that there may even exist bedrock occurrences of Upper Triassic or Lower Jurassic bauxites. In this light, it may be of interest to investigate the margins of coal-bearing basins, from which the sediments were derived, where the Triassic or Lower Jurassic deposits are underlain by Paleozoic quartzless or low-quartz aluminosilicate rocks.

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THE USE OF THE ARGON METHOD IN DETERMINING THE AGES OF CLASTIC SEDIMENTARY ROCKS

by

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Since clastic sedimentary rocks (gravel, sands, sandstones and many clays) preserve the argon-potassium ratio of their source material, the argon method of determining the ages of sedimentary rocks may be used in paleogeographic reconstructions. Newly formed syngenetic clay minerals are probably most suitable for determining the ages of sedimentary formations.

* * * * *

In applying any method of radioactive age determination to the minerals of igneous rocks or syngenetic sedimentary minerals, we are actually determining the time of formation of these minerals, which usually coincides with the time of formation of the rocks containing them. In determining the ages of epigenetic minerals, we are determining the time of the epigenesis.

These things are clear and not controversial. But if we are to attempt to determine the age of residual (clastic) minerals in sedimentary rocks, doubts may well arise as to the sense of such determinations, as well as their reliability. Such doubts are quite natural and proper. The question of the possibility of using accessory minerals from concentrates for radioactive age determination has already been considered in a number of papers (2, 3). We have also presented some data on the use of pebbles, sands and sandstones (4).

At the present time we possess a considerably greater amount of information and may consequently quite properly discuss this question from the standpoint of methodology. In determining the age of clastic rocks by the argon method, we are determining not the time of deposition of the given bed, but the age of the potassium-containing minerals of the original igneous or metamorphic rocks.

Such a question may arise in solving certain paleogeographic problems. Sometimes the area from which the material was transported in the deposition of a given formation may be unclear. If there are varieties suggesting transportation of material from formations of different ages, a determination of the ages of the minerals in the sedimentary series will answer this question. When the sediments have been formed from materials from different sources, it is thereby possible to calculate the approximate percentages of the materials from one source or another of a given age.

But the problem can also be considered from another standpoint. In studying the change in the Ar^{40}/K^{40} ratio in the minerals of sedimentary rocks, we may judge the state of their preservation, metamorphism, the sizes of the unit blocks of crystalline material, etc. But a solution of such problems requires clear concepts of the changes in the argon-potassium ratio during the process of weathering, the transportation of the sediment and its "life" as a sedimentary formation. This aspect of the matter has not been studied at all. The present article will attempt to approach an analysis of it from two standpoints: 1) a consideration of the "argon age" of various types of sedimentary clastic rocks, when the age of the source material is known; 2) tracing the change in the argon-potassium ratio during the process of disintegration of a granite and migration of the products of this disintegration. This will quite naturally require long and thorough investigation.

This paper is only a first attempt to draw certain tentative conclusions from particular examples. As already mentioned above, in such an investigation it will be necessary to choose an area with source material of one uniform age, and we have therefore chosen the region of the Central Tyan'-Shan', where the chief mass of igneous rocks consists of Caledonian granitoids about 340 million years old (5). The possible admixture of fragments of

[1]Primeneniye argonovogo metoda opredeleniya vozrasta k oblomochnym osadochnym porodam.

Table 1

The Age of Caledonian Granite Pebbles of the Tien Shan[1]

Sample No.	Size, cm	Type of deposit	Place	K, %	Ar $см^3/g \cdot 10^{-5}$	Age, million years
		Gray porphyritic granites (340 million years)				
1	3—6	Lacustrine	Tossor River	3.80	6.18	360
2	4—8	Fluvial	Barskaun River	2.40	3.85	355
3	3—8	"	Tossor River	3.21	4.62	325
4	20	Glacial	Barskaun River	3.86	6.17	355
5	50	"	Dzhyrgalan River	3.73	5.73	345
6	30	"	"	3.64	4.93	310
7	5—10	Conglomerate Q	Barskaun River	3.03	4.46	330
8	1—3	" Tr	Village of Dzhety-Oguz	3.18	4.52	320
9	5	" C	Chu River	1.38	2.23	355
		Red alaskite granites (330 million years)[2]				
10	3—5	Fluvial	Village of Dzhety-Oguz	3.65	4.42	275
11	3—8	Lacustrine	Village of Kaysara	4.00	6.08	340
12	5—7	Conglomerate Q	Village of Dzhety-Oguz	4.01	5.09	290
13	3—5	" Tr	Village of Dzhety-Oguz	3.23	3.72	265

[1] In this table and elsewhere the ages have been calculated using the value $\lambda k = 6.02 \cdot 10^{-11}$ years^{-1}.
[2] It is not impossible that the pebble investigated here may have been formed of alaskites of various ages.

metamorphic rocks is here also of the same, or Caledonian, age (6). Consequently for the clastic rocks formed out of material transported from a quite extensive territory, the source material is generally of the same age. In the case of the disintegration products of the granitoids this condition is easier to meet, since in this case it is possible to use material from the basins of rivers that cut through rocks of a single age.

The greater part of the rocks investigated by us were taken from the northern slopes of the central part of the Terskey Ala-Tau Range, and some of them from the Susamyr Mountains and the Kungey Ala-Tau. Individual specimens of rocks were taken from other areas.

The Central Tien Shan contains Caledonian granitoids that are mainly of two types:

1. Gray (frequently porphyritic) granites and granodiorites, with a predominance of biotite-amphibole granite in which the amount of plagioclase is usually greater than that of the potassium felspar. This granite is relatively stable in the process of weathering.

2. Red medium-grained alaskite granites. Here the potassium felspar (microcline and perthite-microcline) predominates over the plagioclase. The plagioclase is acidic. The granites are frequently altered by post-magmatic processes and therefore have a somewhat more friable structure.

The gray porphyritic granites occur in much greater amount that the red alaskites and form the chief mass of Caledonian granitoids. Hercynian and Proterozoic (?) granitoids play a very subordinate role in the totality of clastic material. In choosing particular subjects for study, we have avoided areas where these granitoids are developed.

Let us now consider the various types of clastic rocks occurring as a result of disintegration of the Caledonian granite of the Central Tien Shan.

I. GRANITIC GRAVELS

The largest (in particle size) fragments of granite rocks, transported to great distances from the place of their formation, are gravels. Geologists frequently use the occurrence of granitic gravels in sedimentary rocks as an indication of the age relationships of the igneous and sedimentary rocks, or to point to the source of the material of which the sedimentary rocks are composed.

Such determination of the "kinship" of the gravels with the granites is usually based on petrographic analogy. But this criterion is not always reliable, since the petrographic composition of the rocks in granitic complexes frequently is highly variable. A determination of the absolute age of the gravels may in such cases serve as an additional objective criterion in discovering their origin. But to what extent is the argon-potassium ratio maintained in gravels—the products of lengthy transportation in a water medium?

Table 2

Sands and Sandstones of the Tyan'-Shan'

Sample No.	Rock	Place	K, %	Ar $cm^3/g \cdot 10^{-6}$	Age Million Years
1	River Sand	Dzhety-Oguz River	4.00	4.60	270
2	"	Barskaun River	2.78	4.24	340
3	"	Tossor River	3.40	5.21	340
4	Lacustrine Sand 1–2 мм	Lake Issyk-Kul', Cape Kurumdu	4.56	5.99	300
5	" 1–0.2 мм	Same	3.21	4.37	310
6	1–2 мм	Barskaun River	3.51	5.29	335
7	" <1 мм	" "	2.83	4.72	370
8	Sandstone Q_1	" "	4.43	7.52	375
9	" Kz	Composite sample, Terskey	2.98	5.03	370
10	"	Composite sample, Central Tyan'-Shan'	2.89	4.21	330
11	" Tr	Composite sample, Dzhyrgalan R.	3.01	3.61	280
12	"	Dzhyrgalan River, ore lump I	3.18	5.10	355
13	"	Dzhyrgalan River, ore lump II	2.30	2.58	255
14	"	Dzhyrgalan River, ore lump III	2.15	2.89	305
15	"	Dzhety-Oguz River	3.09	3.38	250
16	Siltstone Tr	Agulak River	1.45	2.2	340
17	Sandstone J	Dzhyrgalan River	1.59	2.36	330
18	Sandstone	Dzhyrgalan River	2.12	3.17	335
19	Gravelite J	Village of Dzhety-Oguz	0.61	0.95	350
20	Sandstone C	Composite sample, Central Tyan'-Shan'	1.89	2.79	330
21	"	Dzhyrgalan River	3.53	5.30	335
22	"	Dzhyrgalan River	2.09	2.63	290
23	"	Dzhyrgalan River	2.59	4.01	345
24	"	Dzhety-Oguz River	1.53	1.89	280
25	"	" "	2.09	2.61	285
26	"	" "	1.69	2.40	320
27	"	Boyamskoye Pass	3.67	4.95	305
28	"	" "	3.28	4.32	300
29	"	" "	1.89	2.79	330
30	"	Karakiche River	1.91	2.48	295
31	"	Agulak River	1.73	2.90	370
32		Kyzyl-Suyek River	2.97	5.17	380

Table 1 shows the results of determinations of the ages of gravels of various origins within the two main varieties of Caledonian granites of the Terskey Ala-Tau Range.

The table shows that the argon-potassium ratio is excellently maintained in all the gravels of the gray porphyritic granites. Their ages coincide fully with those of the source granites, and vary only within limits that are normal for well-preserved granites.

The pebbles of the red alaskite granites in most cases give somewhat lower ages (15 - 20%), because of the lower stability of their granites in the process of weathering. Monoliths of such granites taken from natural outcrops in certain cases give ages that are lower by the same order of magnitude. Thus the examples cited, on the one hand, indicate a satisfactory correspondence between the ages of the gravels of various origins and the source granites and, on the other hand, show the need for giving some attention to the possibility of a certain "by gravels" lowering of the age for granites altered by post-magmatic processes.

II. ARKOSIC SANDS AND SANDSTONES

Table 2 shows the results of age determinations of various sands and sandstones. Almost all the specimens were taken from the basin of Lake Issyk-Kul', and some samples of ancient sandstones from the area of the Susamyr Range and the Boamskoye Pass.

The table shows that the greater part of the specimens correspond completely or very closely in age to the Caledonian granitoids (340 million years). Consequently all the sands and sandstones in this case as a rule retain the argon-potassium ratio of the source rocks.

Table 3

Arkosic Sands and Granites of Southern Karelia[1]

Sample No.	Rock	Place	K, %	Ar $cм^3/g \cdot 10^{-6}$	Age, Million years
1	Rapakiwi granite	Vyborg massif	5.88	5.3	1450
2	Felspathic fraction of Rapakiwi granite	" "	7.83	6.5	1370
3	Granites	Central Karelia	—	—	1420
4	Granites of IVth magmatic cycle		—	—	1300
5	Rapakiwi granite	Pitkaranti	4.30	3.86	1450
6	Glacial sand	Zelenogorsk	3.40	2.9	1400
7	" "	Village of Komarovo	2.5	2.2	1430
8	Littoral sand (<0.5 mm)	Mouth of Neva River	2.34	1.82	1310
9	Littoral sand (0.5 - 2 mm)	Mouth of Neva River	2.48	1.95	1320

[1]Samples 1 - 4 from E. K. Gerling (1).

But in spite of this relative uniformity of age, there are some noticeable deviations, which require explanation.

Modern sands will be considered somewhat later, in the section on the weathering of granites. In regard to the sandstones, one may first of all note the close correspondence between the ages of composite Cenozoic samples (Samples 9, 10) and also Carboniferous (Sample 20) sandstones and Caledonian granitoids. Consequently in these types of rocks the argon-potassium ratio is generally preserved. The composite sample of Tertiary sandstones, like the individual samples of these rocks, give somewhat lower age values. This is apparently due to the fact that these sandstones are composed of rather friable, highly weathered material (redbed deposits), in which there is a small amount of newly formed clay minerals. The same explanation probably applies to certain samples of Carboniferous sandstones, which give somewhat lower ages. Naturally the question will arise as to how far this experiment can be applied to other areas, with other types of weathering and sedimentation of the deposits. This question is partially answered by the data from the sandstones of four age groups used by us (Carboniferous, Jurassic, Tertiary, Quaternary), whose formation took place under various climatic and geologic conditions.

As still one more example, let us consider some samples of glacial and marine littoral sands from the vicinity of Leningrad (Table 3). Samples 6 and 7 were taken from canals in the vicinity of Zelenogorsk and Komarovo; these are typical fluvioglacial deposits. Samples 8 and 9 were taken from the seashore at the mouth of the Neva River; these are sands that have been repeatedly redeposited and transported in glacial times and during regressions and transgressions of the Baltic Sea. Nevertheless the ages of all four samples are very close to the ages of the source granites (Samples 1 - 5).

III. CLAYS

The study of clays and oozes, in order to determine the argon-potassium ratios in them, would at first glance appear to be a pointless and unsuitable task, the more so because separation of the radiogenic argon from many types of clays sometimes encounters great technical difficulties. Nevertheless the relatively small number of experiments performed by us have produced curious and encouraging results (Table 4).

Before considering the table, let us recall that there are quite contradictory concepts of the genesis of clays and their mineralogical composition. Along with views which see clays as rocks consisting of very tiny fragments of crystals, there are those that regard them as being of chemical origin. There are, naturally, also views intermediate between these two extremes. In nature one inevitably encounters various types of clays, some of which have been thoroughly described. Pure representatives of one clay mineral or another are rarely

Table 4

Argon-Potassium Ratios in Certain Clays

Sample No.	Rock	Place	K, %	Ar cm^3/g10^{-5}	Age, million years
		I. Central Tyan'-Shan'			
1	Gray clay J_1	Dzhyrgalan River	3.67	4.73	295
2	" "	" "	3.05	3.81	285
3	" "	" "	3.62	5.50	340
4	Gray clay J_1	Soguty River	1.74	2.70	350
5	" "	" "	1.66	2.66	355
6	Yellow Clay J_1	" "	1.87	2.86	340
7	" "	Minkush River	2.97	4.26	325
8	Recent clay	Barskaun River	2.68	3.70	310
		II. Karanganda Basin			
9	Gray argillite J_1	Verkhnesokura trough	2.12	3.44	360
10	Kaolinite clay J_1	Mikhaylovskaya trough	2.13	1.86	200
11	Yellow argillite	" "	1.98	2.74	310
12	" "	" "	1.71	2.50	330
		III. Leningrad			
13	Blue clay cm	Subway	3.35	8.81	555
14	" "	"	3.27	9.68	610
15	Redeposited clay	Novaya Derevnya (canal)	1.51	4.31	600
		IV. Oceanic oozes			
16	Red ooze (depth 5500 m)	Pacific Ocean (Station 3156)	2.36	1.52	150
17	"Iceberg ooze"	Indian Ocean shores of Antarctica	3.22	6.13	420
		Deposits of kaolinite clays			
18	Kaolinite clays	Chasovyarskoye	1.39	2.11	340
19	" "	Arkalykskoye	0.8	0.51	150

encountered, and one usually is faced with mixtures that are hard to identify. Thus it is possible that the argon method of determining age may produce additional information in discovering the genesis and structures of clays.

Let us now turn to the table. Let us consider the Jurassic clays of the Central Tyan'-Shan': these are typical oily, finely ground clays from coal-bearing deposits. Their mineral composition has not yet been studied. We have investigated clays from three different areas some hundreds of kilometers away from each other.

The ages of five samples of clays (Samples 3 - 7) turned out to be entirely the same and exactly equal to the age of the Caledonian granitoids, and also to the time of metamorphism of the ancient sedimentary rocks. In this case there can only be one answer—the Jurassic clays of the Central Tyan'-Shan' are (to a considerable degree) a mechanical sediment. They consist of very tiny fragments of crystals of Caledonian granitoids or metamorphic rocks. Of course such a categorical statement can only be made of the potassium-containing minerals in the clays.

In addition, two samples from Dzhyrgalan (1, 2) gave lower age values that were almost Hercynian; this may be explained: 1) by an admixture of Hercynian material, 2) by an admixture of potassium-containing newly formed clay, and 3) by the loss of argon. This case requires additional study.

Sample 8 is a modern clay with a small admixture of sandy material. Although it is a present-day redeposited formation, its age is also close to Caledonian.

Let us now examine certain specimens of Jurassic argillites from the Karaganda basin. Three of them (Samples 9, 11, 12) gave ages that were close to Caledonian. Under the microscope it was seen that they consist mainly of a pelitomorphic mass, with clearly distinguishable tuffaceous fragments and individual small crystals of kaolinite. These argillites are clearly of mixed origin, but the predominant component in them is evidentally a clastic material of Caledonian age.

Sample 10 is of particular interest. This is clearly a kaolinite clay: in thin sections one can see that it consists mainly of kaolinite flakes. Its age has been determined as 200 million years. According to the presently established scale of absolute geologic time, this is Permian and not Jurassic (when these rocks were deposited). This discrepancy has two explanations: 1) the existing scale of geologic time in a number of cases contains certain discrepancies, such as an increase in Hercynian ages; this may also apply to the Early Mesozoic; 2) the age value has also quite likely been increased by an admixture of Caledonian clastic material.

As one more example, let us examine the Cambrian blue clays of Leningrad. The two specimens of these clays were taken from the Leningrad subway (Samples 13, 14), and a third (Sample 15) from canals at the surface of the ground, and are apparently redeposited formations. The ages of all three samples are quite close, about 600 million years—that is, Late Proterozoic. These clays consist primarily of clastic material with an admixture of glauconite. This case requires further and more detailed study.

If clays consist of fragments of crystals containing radiogenic argon, many types of modern oozes will probably also contain radiogenic argon. To test this supposition, we have investigated a specimen of red, deep-water ooze from the Pacific Ocean. This sample was taken from a depth of 5500 m (station 3156, "Ob'"). Table 4 shows the results of the analysis. It must be said that this analysis is not completely accurate, since the sample contained a considerable admixture of atmospheric argon, but we determined the approximate order of the age of the source material: this is 150 million years, corresponding to the Jurassic What does this figure signify?. Considering that deep-water oceanic oozes are formed of tiny particles in suspension, transported for great distances from different continents, it may be supposed that in determining their age we are determining the average age of the potassium minerals of the Pacific Ocean province, in a modern erosional section. This is only a tentative assumption, an illustration indicating the possibility of elaborating such a problem. (This age is quite likely somewhat lower than it should be because of the admixture of newly-formed minerals.)

Another interesting example is provided by Sample 17—"iceberg sediments". This is a fine rock-flour ooze, deposited by icebergs near the shores of Antarctica in the southern part of the Indian Ocean. The age of this sample is 420 million years—close to the age of the granitoids and metamorphic rocks of the Mirniy region.

The experiments performed by us are of interest not only for the possibility of determining the age of the source material in oozes, but also for the fact of the preservation of radiogenic argon in the tiny ooze particles. Since it appears that the argon is preserved in tiny ooze particles and that all the clays investigated by us (except for Sample 10) have ages not of newly-formed clays, but close to those of the source material, the question arises as to what proportion of clays are new chemical formations. As a preliminary attempt, we have investigated two samples of typical kaolin clays, taken from known deposits of refractories (Table 4, Samples 18 and 19). The clay specimen from the Arkalyk deposit consists (according to the Institute of Refractories) of 70% kaolinite and 10 - 15% gibbsite; its age, as determined by us, is 150 million years, corresponding to the Cretaceous, which is geologically quite sound. The age may be somewhat exaggerated because of the clastic material, but most of the radiogenic argon was formed and preserved in the kaolinites.

The clays of the Chasovyarskiy deposit are of Caledonian age, indicating that a considerable part of the potassium-containing clay material is not syngenetic newly-formed clay, but represents tiny fragments of ancient potassium-containing minerals.

IV. CHANGE IN THE ARGON-POTASSIUM RATIO IN THE DISINTEGRATION OF GRANITES AND THE MIGRATION OF THEIR DISINTEGRATION PRODUCTS

Since the preceeding sections of this paper have shown that the argon-potassium ratio shows no essential changes even in the extreme products of disintegration of granitoids —arkosic sands and clays—the question naturally arises as to the stability of this ratio in various stages of weathering and transportation of the disintegration products.

In answering this question, let us consider the case of disintegration of the gray porphyritic Caledonian granite (Table 5). Specimens were taken from the valley of the Barskaun River, a tributary flowing into Lake

Table 5

Disintegration of Granite (Deluvial Type of Weathering, Followed by Stream Transportation and Reworking by Lake Wave Action) Gray Porphyritic Granites of the Barskaun River Region

Sample No.	Rock	Particle diameter	K, %	Ar cm^3/g10^{-5}	Age, million years
1	Monolithic granite	—	3.01	4.82	355
2	" "	—	3.43	5.09	330
3	Strongly weathered granite	—	3.56	4.94	310
4	Deluvium (gravel)	1—5 см	3.0	3.03	235
5	Deluvium (sand)	3—10 мм	2.91	3.15	250
6	Deluvium (fine sand)	0.3—0,5 мм	2.43	3.34	310
7	Fluvial sand	0.3—0,5 мм	2.78	4.24	340
8	Fluvial gravel	4—8 см	2.40	3.85	355
9	Glacial gravel	20 см	3.86	6.17	355
10	Lacustrine sand (river mouth)	1—2 мм	3.51	5.29	335
11	Lacustrine sand (river mouth)	<1 мм	2.83	4.72	370
12	Lacustrine conglomerate Q (gravel)	5—8 см	4.43	7.52	375
13	Deltaic clay	<0.1 мм	2.98	4.11	310

Issyk-Kul'. This river cuts through Caledonian granites of uniform age, so that we may be sure that we are following the different stages in the migration of one and the same rock.

Let us consider Table 5. When there are clear traces of weathering, the granite loses about 10% of its argon, and the granitic deluvium, representing fragments of highly weathered granites, from 10 - 30% of its argon. Characteristically, the largest fractions of deluvium have lost the greatest amount of argon.

Fluvial and lacustrine sands and gravels have the same argon-potassium ratio as unaltered granites, and in the lacustrine varieties it may be even somewhat higher. This regulatity may be explained by "natural selection". The material that was weak and unstable in the stage of deluvial weathering was removed in the working of the sediments by river currents and the surf at the shores of the lake. The more stable fresh material was preserved.

Sample 13, a deltaic clay, is of particular interest. Its age is approximately equal to that of the granite, and the age of the Jurassic clays of the same region corresponds even more closely to that of the granites (see above).

Let us consider several cases of disintegration of granites at the site of their weathering (Table 6).

The first case involves Hercynian alaskite granites of Ortotokoy. Two specimens were analyzed: a monolithic, quite fresh specimen of granite, and its eluvium, formed on a gentle slope and covered above by a layer of sandy soil. The eluvium represents granite that has disintegrated to the point of becoming arkosic sand; its age, in comparison to the source granite, shows a decrease of only 10%.

The second case involves a granite from Cape Kurumdu on the shores of Lake Issyk-Kul'. Here the disintegration of the granites took place on a lake terrace, and its fragments were broken up in place and sorted by water currents at the shore of the lake. The age of the arkosic sands turned out to be 5 - 10% lower than that of the granites. This in no way contradicts the example described above, in which the age of the lacustrine sands was even somewhat greater than that of the granite, which was explained by the selective preservation of the best felspar material. The apparent contradiction here is explained by the fact that, in the case of in situ reworking of the products of disintegration of the granites, the material was not yet sufficiently sorted.

Considerable interest attaches to the third case of eluvial weathering of granites, illustrated by their disintegration in situ with a considerable pelitization of the felspar. The granites under consideration (Samples 2 - 6) are part of the ancient (Jurassic) weathering crust. At the present time they occur at the crest of a small watershed and are preserved

Table 6

Disintegration of Granites at the Weathering Site

Sample No.	Rock	Particle diameter, mm	K, %	Ar $cm^3/g10^{-5}$	Age million years
	I. Hercynian alaskite granites of Ortotokoy				
1	Monolithic granite	—	3.98	4.28	250
2	Eluvium beneath layer of soil	0.5—2	3.30	3.15	220
	II. Caledonian granites of Kurumdu (disintegration and sorting by surf in situ)				
1	Gray granite	—	2.56	3.79	335
2	Red granite	—	3.95	5.76	325
3	Mixed lacustrine sand	1—2	4.56	5.99	300
4	From both types of granites	1—0.2	3.21	4.37	310
	III. Weathering with considerable "pelitization" of felspar (Soguta)				
1	Monolithic granite	—	4.14	27.5	385
2	Strongly pelitized granite	—	4.60	6.08	300
3	Granite	—	4.50	7.7	380
4	Pelitized granite gravel	30—0.25	6.68	11.55	380
5	" " "	<0.25	5.90	9.04	340
6	" " "	<0.005	5.005	8.62	375

in monolithic state. They are considerably weathered, and are readily broken up, so that many felspar crystals fall into tiny fragments; under the microscope the granites have the appearance of a pelitomorphic mass. Nevertheless even under this intensive weathering, the argon-potassium ratio is in all samples fully preserved, and is observed to be somewhat lower only in Sample 2.

Special note should be taken of the fact that this ratio is maintained in the fine rock-flour fraction of kaolinized granites (particle size < 0.005 mm). In this light it is of interest to consider two more analyses of the fine fractions of clays and felspars (Table 7).

The rock flour fraction of particle size < 0.002 mm (on the order of a "subcolloidal" fraction) was taken from a Jurassic clay (Table 4, sample 7). This was vaporized and heated at 200° C. Nevertheless the argon-potassium ratio in it was fully preserved. The situation is somewhat different with the light fraction taken from comparatively unaltered gray Caledonian granites. Almost all the potassium here is contained in the felspars. In this case, some loss of argon was observed in the fine fraction.

It is important that the argon is retained in the very tiny clay particles, whose sizes approach of colloids. These facts may be understood on the basis of the theory of the block structure of felspar crystals. The sizes of the unit blocks correspond to those of the "subcolloidal fraction." These unit blocks are completely finished, whole and stable microcrystals of felspars, and contain radiogenic argon. The loss of argon in the first levels of weathering is probably due to the initial stages in the disintegration of the crystal into its unit blocks, when the bonds between the blocks are broken. This explanation may provide the key to understanding the constant ratio between the ages of micas and felspars.

CONCLUSIONS

1. In the majority of cases granite gravels, arkosic sands, sandstones and clastic clays preserve an argon-potassium (Ar^{40}/K^{40}) ratio corresponding to the age of the source material. Consequently this circumstance may be used in paleogeographic reconstructions and as a supplementary criterion in the correlation of sedimentary rocks.

2. The single case of kaolinite clays investigated indicates that radiogenic argon is preserved in the kaolinites; this can thus be of use in determining the time of their formation. This problem requires further

Table 7

Ages of Different Fractions of Clay and Felspar

Sample No.	Rock	Fraction, mm	K, %	Ar cm^3/g10^{-5}	Age, million years
1	Clay J	monolith	2.97	4.26	325
2	"	>0.002	2.70	4.03	335
3	"	<0.002	3.05	4.52	330
4	Felspar of Caledonian granites	2—0.2	3.82	5.41	320
5	Same	<0.002	3.70	4.32	280

elaboration, both for kaolinites and for other clay minerals. Some of them (for example, hydromicas) may preserve the age of their primary crystallization.

3. In the disintegration of granites one observes a contradictory process, leading to changes in the argon-potassium ratio. In the initial stages of weathering the loss of argon is more rapid than the loss of potassium, but in the final stages this difference disappears, and the ratio of argon to potassium again reaches the same magnitude as in fresh rocks. Study of this phenomenon may help in understanding the mechanism of disintegration of crystals in weathering.

4. Special stress must be laid on the fact of the preservation of the Ar^{40}/K^{40} ratio in the tiny "subcolloidal" particles of clays, oozes and the local disintegration products of felspars. This fact may support the block theory of the structure of felspar crystals, and is also useful in understanding the conditions of formation of hydromicas and other clay minerals.

5. This article has touched upon quite a large number of questions. The facts cited are still insufficient to provide a reliable basis for a number of the conclusions drawn. This will require long and thorough investigations of sedimentary materials of different origins. Here we have merely posed the question, but our first attempts at a study of the argon-potassium ratios in clastic sedimentary rocks indicate that such investigations may be quite fruitful.

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ON THE GENETIC CONNECTION BETWEEN TIN MINERALIZATION AND SUBVOLCANIC ROCKS (ON THE EXAMPLE OF THE SOUTHERN PRIMOR'YE)[1,2]

by

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In the basin of the Daubikhe River the present author has made a detailed study of a stock of felsites, quartz porphyrites and granite porphyries, representing subvolcanic formations, which provides an example of the genetic connection of such rocks with later tin ore mineralization.[2]

The area within which the above-mentioned stock is exposed according to P. N. Kropotkin, is part of the Daubikhe synclinal zone, a belt of intensively dislocated Late Paleozoic and Mesozoic (pre-Cretaceous) deposits, extending for 400 km toward the northeast from the Amur Gulf to Iman. In the east this zone borders on the principal Sikhote-Alin' anticlinorium, and in the west on the Khankay tectonic massif. The Daubikhe synclinal zone is characterized by the development of marine Triassic and Lower Jurassic deposits, occurring in the core of the syncline and crumpled into a series of large linear folds trending northeast. These folds are accompanied by faults whose strikes are northeast, northwest and nearly parallel to the equator. These fractures were the paths along which the igneous melts and ore solutions traveled; especially favorable paths for the latter were places where there was an intersection of dislocations in two directions—northwest and northeast.

In the northern part of the Daubikhe zone, the Upper Triassic deposits are cut by medium-grained, frequently porphyritic diotite granites with a large amount of miarolitic cavities, as well as small stocks and dikes of felsites and quartz porphyries. These granites have been named the Mar'yanovskiy granites and described in detailed in another paper by the present author (5); the present article will present a brief description of the felsites, the quartz porphyries, and their relationship to the rare-metal mineralization.

Geologic-petrographic study of the felsites, the quartz porphyries and their lava breccias, special investigations of the accessory minerals and the chemical elements of admixtures in these rocks, as well as the discovery of the nature of their relationship to the rare-metal mineralization, have made it possible to determine the petrochemical features of these rocks, to prove their genetic association with rare-metal mineralization and to consider them as subvolcanic formations. Comparison of the petrochemical properties of these subvolcanic rocks with the Mar'yanovskiy granites has suggested that they are associated with the latter genetically, and are the products of a further development of the same magma chamber from which the Mar'yanovskiy granites were formed.

GEOLOGIC AND PETROGRAPHIC CHARACTERISTICS OF THE FELSITES AND QUARTZ PORPHYRIES

The felsites, quartz porphyries and granite porphyries occur as a small stock, about 0.4 km^2 in area, and as dikes from tens of centimeters to tens of meters in thickness, trending northeast and northwest. The latter are the thickest and can be traced for a great distance. The above-mentioned stock is controlled by the fissures trending northwest; its western contact is steep, dipping southwestward at an angle of 70°, while its eastern is more gentle, dipping eastward at 40 - 50°.

The felsites, quartz porphyries and granite porphyries intersect and metamorphose the sedimentary deposits of the Norian stage (T_3), lithologically represented by polymict and tuffaceous sandstones, siltstones and argillites.

The upper age boundary of the felsites and quartz porphyries has not been established. Determinations of the absolute age of the felsites,

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[1] O geneticheskoy svyazi olovyannogo orudeneniya s subvulkanicheskimi porodami (na primere Yuzhnogo Primor'ya)

[2] The tin-ore occurrences located in the exocontact zone of these subvolcanic rocks have been studied in detail by I.A. Borodina, N.N. Vasil'kova, N.P. Zabolotnaya and V.T. Shatskiy.

made by N. I. Polevaya in the All-Union Geological Institute (VSEGEI) by the argon method have given 80 million years, corresponding to the Late Cretaceous. These figures were obtained in determinations of the absolute age of the Mar'yanovskiy granites.

The contacts between the felsites and the enclosing sandstones are uneven (Figure 1). At the western contact of the stock one may

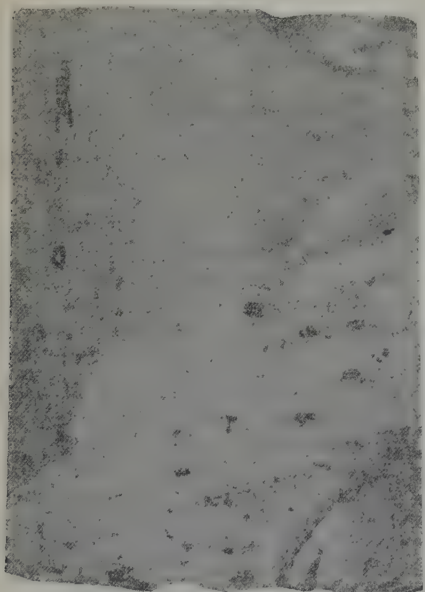

FIGURE 1. Contact between felsite and sandstone. Specimen 4251.

observe very fine injections of felsites in the surrounding sandstones, testifying that they were intruded under pressure. In the same sandstones, near the western contact of the felsitic stock, there is a large number of quartz-chlorite and chlorite veins and veinlets, usually containing cassiterite.[3] In places these veinlets appear in the stock itself. At the contact with the quartz-chlorite veinlets, both the sandstones and the felsites are altered to quartz and chlorite, and more rarely greisenized.

At their contacts with the felsites, quartz porphyries and granite porphyries, the sandstones are also usually somewhat quartzified and chloritized, and sometimes slightly greisenized. In these altered sandstones one may observe cavities filled with druses of quartz together with chlorite, fluorite and cassiterite.

According to this writer's observations, the stock in question is composed chiefly of felsites and quartz porphyries, interlayered at the periphery with brecciated lavas of quartz porphyries. Within the stock, the granite porphyries have a limited distribution, being associated with its central parts and showing gradual transitions, like the quartz porphyries, to the felsites, which are here the most widespread. The felsites are quite dense light-gray and yellowish-gray rocks, sometimes showing clear flow structures. Frequently the felsites contain miarolitic cavities (Figure 2), filled with druses of quartz (in some parts, morion), felspars and sometimes cassiterite (Figure 3). Studies with the microscope have shown that the felsites consits mainly of quartz, potassium felspar and albite. Biotite is sometimes present in small quantites. Accessory minerals are zircon, rutile, apatite, ore minerals and cassiterite.[4] The secondary minerals are chlorite, sericite, zoisite, and clinozoisite.

The structure of the rock is felsitic[5] or micropoikilitic; in some areas the rock is observed to have a porphyritic structure (Figure 4).

It has already been mentioned that along with the felsites, there is also quartz-porphyry in the stock and more rarely in the dikes. The latter differs from the above-described felsites by the presence of porphyritic segregations of quartz, potassium felspar (non-lattice) and albite-oligoclase, and from the felsite porphyries by the presence of porphyritic segregations of quartz. The total quantity of porphyritic segregations in the quartz-porphyries varies from 3 to 12%, quartz being the predominant mineral in them.

The groundmass of these rocks consists of very tiny grains of quartz and felspars, as well as little flakes of chlorite. The structure of the groundmass is felsitic or micropoikilitic and only in particular cases micropegmatitic, because of the close intergrowth of potassium felspar and quartz. Accessory minerals, as in the felsites, are present in small amounts and are represented by zircon, rutile, an ore mineral and cassiterite. In a number of areas the felsites and quartz-porphyries alternate

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[3] The results of spectrum analyses of this cassiterite are given in Table 5.

[4] Prepared concentrates of the felsites in addition to the above-mentioned minerals, have contained orthite, fluorite and tourmaline. In one concentrate were found single grains of fergusonite.

[5] Wherever the structure of the ground mass is felsitic, in addition to the minerals, there is a small quantity of volcanic glass.

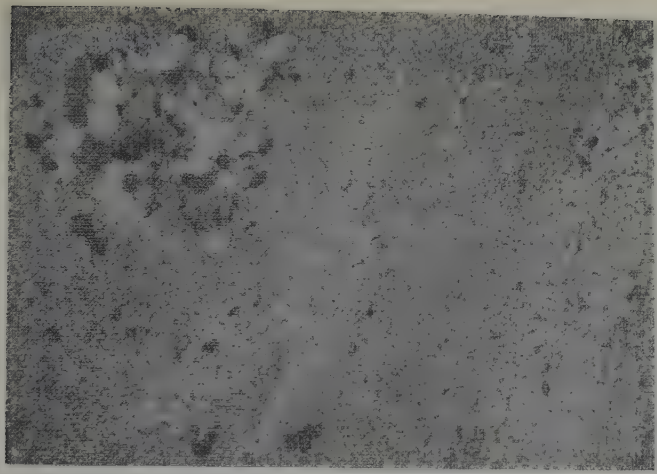

FIGURE 2. Felsite with miarolitic cavities. Thin section 4257, magnification x 20, with crossed nicols.

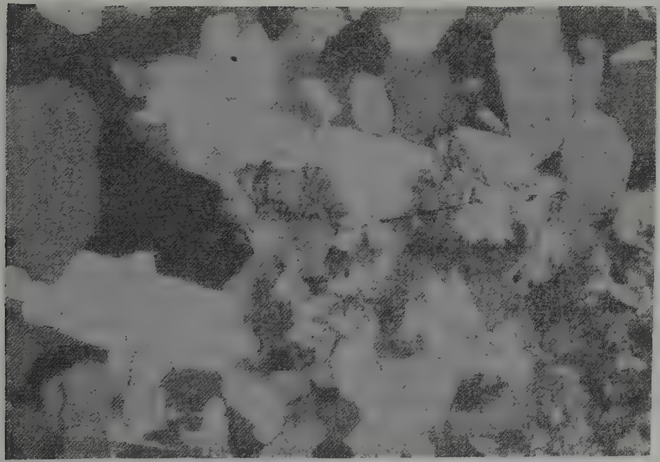

FIGURE 3. Miarolitic cavities with cassiterite. Thin section 4257, magnification x 90, with crossed nicols.

with quartz-porphyry lava breccias, the greatest amount of which occurs on theperiphery of the stock.

It can be seen under the microscope that the lava breccias consist of fragments of polymict sandstones, of argillaceous, quartz-sericite and quartz-chlorite shales, felsites, quartz, potassium-felspar and plagioclase. The fragments are angular in shape, and often the fragments of several rocks and minerals, especially of the polymict sandstones, are fused. The rock fragments are 0.2 - 7 mm in cross-section, but the minerals no more than 1 mm. The amount of fragments ranges from 15 - 40%. The lava breccias show clear flow structure. All the fragments are contained in the groundmass of the rock, consisting of very tiny grains of quartz and felspars with an admixture, which is sometimes considerable, of chlorite. The structure of the groundmass is felsitic. Here, in addition to the above-mentioned minerals, there are small quantities of tiny zircon grains and acicular crystals of rutile.

The granite-porphyries, as already mentioned, have a limited distribution in the region under investigation and are exposed only in the central part of the stock. The granite-porphyries consist chiefly of quartz, potassium-felspar and plagioclase, with sometimes a small amount of biotite. The accessory minerals are represented by zircon, rutile, apatite, orthite, cassiterite and magnetite, and the secondary minerals by chlorite, sericite, muscovite and a mineral of the epidotezoisite group.

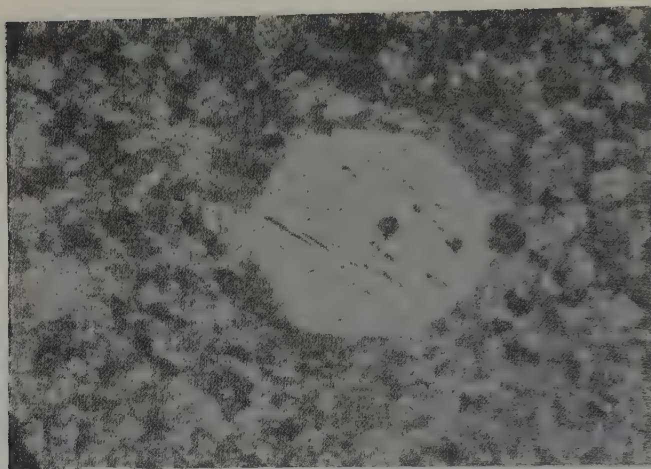

FIGURE 4. Felsite-porphyry. Thin section 4227-a, magnification 46, with crossed nicols.

The structure of this rock is porphyritic; the amount of porphyritic segregations varies from 10 to 30%, represented by potassium-felspar (non-lattice), plagioclase (oligoclase No. 13 - 15 or 25 - 27) and quartz, the first of these three usually predominating. The structure of the groundmass is microgranitic, micropegmatitic or aplitic. In the first case the groundmass consists of idiomorphic crystals of albite-oligoclase, the interstices between which are filled with potassium-felspar and quartz. Besides the minerals just mentioned, the groundmass also contains small amounts of biotite flakes and accessory minerals—zircon, rutile and magnetite. Sometimes isolated crystals of orthite,[6] cassiterite and apatite are encountered. The grains of the minerals in the groundmass vary in size from hundredths to 0.1 and rarely 0.2 mm.

In those areas where the structure of the groundmass is micropegmatitic, it is represented principally by potassium-felspar and quartz, forming intergrowths. Zircon and cassiterite are present in small amounts.

When the structure is aplitic, the groundmass is composed mainly of isometric grains of quartz, potassium-felspar and acidic plagioclase, as well as small amounts of biotite and single crystals of zircon.

In these felsites, quartz-porphyries and granite porphyries one quite frequently observes miarolitic cavities of round (Figure 2) or lenticular shapes (Figure 5), filled with druses of quartz, potassium-felspar, and more rarely albite with admixtures of tiny chlorite flakes. Sometimes the miarolitic cavities, along with the minerals just mentioned, contain single crystals (Figure 4). These cavities are from 0.2 - 3 mm in cross-section, sometimes reaching 6 mm in the granite prophyries.

The cassiterite forms prismatic crystals from hundredths of a mm to 0.1 mm and rarely 0.3 mm in size. In thin sections they are brownish, with a slight pleochroism of brown shades. X-ray analysis of the cassiterite taken from the felsites produced the following results: Nb—1%, Ta—0.1%. Spectrum analysis indicated the following: Be, Y—traces, Nb—medium lines, Sc, Bi—traces, W—medium lines, Cu—very weak lines, Pb—traces, Fe—medium lines, Ti—weak lines, V—traces.

The groundmass around the miarolitic cavities is considerably recrystallized and represented by allotriomorphic aggregates of tiny grains of quartz and felspar with randomly scattered flakes of chlorite and sericite. Here the structure of the groundmass resembles that of hornstone.

In a number of areas the felsites, quartz-porphyries, quartz-porphyry lava breccias and granite porphyries are cut by quartz and quartz-chlorite veinlets, which quite frequently contain cassiterite. At the contacts with these veinlets all the rocks are chloritized, and more rarely somewhat greisenized; the thickness of the contact aureoles around the veinlets varies in relation to the thickness of the latter, but

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[6] In prepared concentrates the content of orthite varies from fractions of a per cent to 25% of the weight of the electromagnetic fraction. The orthite is present as crystals of prismatic habit and grains of irregular shapes, whose sizes range from hundredths of a mm to 0.1 mm, colored dark brown. Semi-quantitative spectrum analysis has shown the orthite to have the following composition (in%): Si, Al-n; Mg-0.0n; Ca-0.n; Be - 0.000n; Y -0.n; Zn, Cu - 0.00n; Fe - n; Tn - 0.n; Mn - 0.0 n; Ce, La - 0.n.

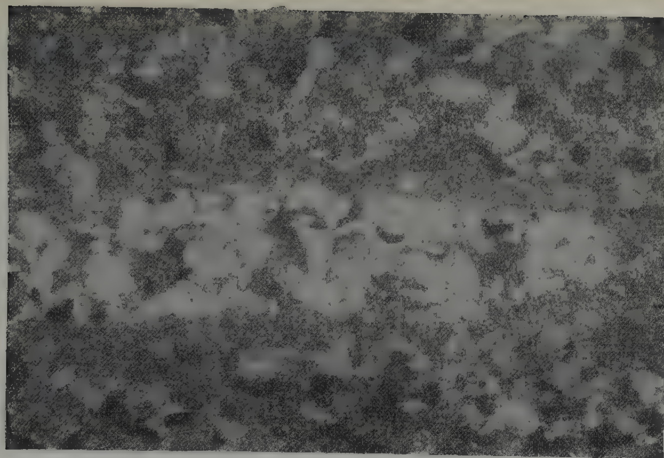

FIGURE 5. Felsite. Lenticular miarolitic cavities with cassiterite. Thin section 4251, magnification x 46, with crossed nicols.

does not exceed 10 cm.

In the chloritized felsites, quartz-porphyries and granite porphyries, the groundmass consists of allotriomorphic aggregates of tiny grains of quartz and felspars with lesser amounts of chlorite flakes. The rock has a hornstone structure. It is observed to contain abundant nodular and vein-shaped accumulations of dark-green, sharply pleochroic chlorite flakes. Usually these accumulations contain tiny grains of cassiterite, colored brown or cinnamon-brown. In certain areas in the central parts of the nodules, together with the chlorite, there are accumulations of relatively large grains of quartz and tiny prismatic crystals of clinozoisite.

The greisenized varieties of felsite consist mainly of very tiny grains of quartz and felspars, flakes and sheets of sericite, muscovite and chlorite. Apart from these minerals, in the greisenized felsites one quite frequently observes tiny grains of fluorite and light-brown cassiterite. Sometimes one may encounter small acicular or long prismatic crystals of cinnamon-brown tourmaline, which may more rarely be bluish. The greisenized felsites have a hornstone structure.

The greisenized varieties of granite-porphyry differ from the granite porphyries that have not been affected by greisenization in containing muscovite, fluorite and greater amounts of cassiterite. The muscovite replaces the biotite and, along with the quartz, also the felspars. The fluorite replaces felspars and biotite. Individual thin sections, along with muscovite and fluorite, contain long prismatic crystals of tourmaline which is brownish and more rarely blue.

The presence of lava breccias among the felsites and quartz-porphyries, and especially the textures of the latter rocks, testify that they were formed at small depths and thus belong to the subvolcanic facies. Their crystallization was probably very rapid, and as a result even the relatively large stock of felsites and quartz porphyries had slight effect on the surrounding rocks, as may be seen from the fact that the thickness of the contact aureoles is never more than a few tens of centimeters. The rapid crystallization of the felsites is also indicated by features of their structure, particularly the presence in individual areas of volcanic glass.

ACCESSORY MINERALS IN THE FELSITES, QUARTZ-PORPHYRIES AND GRANITE-PORPHYRIES

In addition to transparent thin sections, the accessory minerals were studied in specially prepared concentrates produced by breaking up the rock with a ten-kilogram weight and washing the fragments.

The distribution of accessory minerals in these rocks is shown in Table 1. The amounts of one mineral or another in the various fractions was estimated visually. The table shows that the heavy non-electromagnetic fraction of felsites, quartz-porphyries and granite porphyries contained the following minerals (in decreasing amounts): zircon, pyrite, anatase, fluorite, cassiterite, apatite, naegite, arsenopyrite, rutile, galena, scheelite, brookite, barite and leucoxene. In the electromagnetic fraction there were observed (in decreasing order): oxides of iron, garnets, tourmaline, orthite, ilmenite, biotite, sphene

Table 1

Distribution of Heavy Minerals in Felsites, Quartz-porphyries and Granite-porphyries

Names of rocks	In large amounts	Heavy minerals encountered: In small amounts	rarely and in very small amounts	very rarely and as single grains
Felsites	Zircon, magnetite	Pyrite, anatase, pyrrhotite	Cassiterite, fluorite, orthite, tourmaline, ilmenite, garnet	Apatite, arsenopyrite, brookite, rutile, fergusonite, naegite
Quartz porphyries	Zircon, magnetite	Pyrite, anatase, garnets	Cassiterite, apatite, fluorite, tourmaline, pyrrhotite	Galena, barite, scheelite, orthite
Granite porphyries	Zircon magnetite	Fluorite, anatase, orthite	Cassiterite, apatite, pyrite, tourmaline	Rutile, ilmenite, garnets, naegite

and fergusonite. Magnetite and pyrrhotite were usually present in the magnetic fraction.

Of all the above-mentioned minerals, zircon, pyrite, cassiterite, anatase, fluorite, orthite, tourmaline, garnets, magnetite and pyrrhotite are the characteristic accessory minerals in the felsites, quartz-porphyries and granite-porphyries. Comparing the amounts and compositions of the accessory minerals, the felsites, the quartz-porphyries and granite-porphyrites, one sees (Table 1) that in the composition of accessory minerals they are very close to each other, but that the greatest amount of such minerals appears in the granite-porphyries.

PETROCHEMICAL CHARACTERISTICS OF FELSITES, QUARTZ-PORPHYRIES AND GRANITE PORPHYRIES

Four complete silicate analyses of the felsites and granite porphyries and one analysis of the quartz porphyries, and also the results of a number of chemical analyses for alkali, were used to study the petrochemical features of these rocks.[7] Determination of the accessory elements in these rocks involved the use of qualitative and semi-quantitative spectrum analyses of the felsites, quartz-porphyries and granite-porphyries, prepared fractional concentrates of the felsites, as well as spectrum and X-ray analyses of the individual minerals. In order to study the accessory elements in the exocontact zones of the felsites, quartz-porphyries and granite-porphyries, spectrum analyses were made of the unaltered sandstones taken directly from the contact or in its vicinity. The results of these chemical analyses are shown in Table 2, and those of the spectrum analyses of the felsites in Table 3.

Analyzing Table 2 and comparing the results of the chemical analyses of the felsites, quartz-porphyries and granite-porphyries with the compositions of the average rock types according to R. Daly, we see that in their petrochemical properties our rocks approach alaskites, and more rarely occupy intermediate positions between granites and alaskites. The felsites described here differ from alaskites: 1) in their sharp increase in the content of potassium oxide, which varies from 5.16 to 10.15%, with an average of 6.77% as compared to the average of 4.81% for the type alaskite according to Daly; 2) in the sharply decreased content of sodium oxides—from traces to 2.39%, with an average of 0.94% as compared to the average of 3.53% for the alaskite according to Daly; 3) in their decreased content of calcium oxides—an average of 0.27% as compared to the 0.45% for the type alaskite according to Daly.

In comparing the chemical analysis of our quartz-porphyries with the average types of these rocks according to Daly, we see that they approach alaskite, differing from it, like the felsites, in their sharply increased content of potassium oxide and sharply decreased content of sodium and calcium oxides.

Comparison of the chemical analyses of these granite-porphyries with the average rock types according to Daly shows that they also approach the composition of the average alaskite. The

[7] Specimens 11, 5, 10 and 12 were analyzed in the chemical laboratory of VIMS, using material provided by N.N. Vasil'kova, and the remainder in the chemical laboratory of IGEM with material provided by the present author.

Table 2

Results of Chemical Analyses of Felsites, Quartz-porphyries and Granite-porphyries (%weight)

Oxides	Felsites					Quartz-porphyry, Specimen 5	Granite-porphyries			Average comp. of Mar'yanovskiy medium-grained and porphytritic granites	Average composition of alaskite, accord. to R. Daly
	Specimen 4252	Specimen 4226-a	Specimen 11	Specimen 4207	Specimen 4227		Specimen 10	Specimen 5837	Specimen 12		
SiO_2	—	—	75.72	—	75,96	75,64	75.58	—	72.66	75.29	76,47
TiO_2	—	—	0.17	—	0.06	0,08	0.08	—	0,19	0,11	0.07
Al_2O_3			12.55		12.36	12.16	12,93	—	13,29	13,4	13,03
Fe_2O_3	—	—	0,74	—	0.51	0,08	0.00	—	1.40	0.73	—
FeO	—	—	0.47	—	0.05	0.47	1.18	—	1,02	0.78	1,04
MnO	—	—	0.00	—	None found	—	—	—	—	0.01	0,01
MgO	—	—	0.26	—	0.10	0.16	0.11	—	0,21	0,23	0,06
CaO	—	—	0.23	—	0,34	0.12	0,35	—	0.15	0.68	0,45
Na_2O	2.39	0,69	1.40	Traces	0.25	0,93	4.28	3.18	3.39	3.18	3,53
K_2O	6.41	5,96	5.16	6,19	10.15	8.64	3,98	4.74	5.58	5.19	4.81
P_2O_5	—	—	0.02	—	—	0,01	0.03	—	0.04	—	0.01
H_2O	—	—	1.33	—	0,50	0.61	0.50	—	—	0,30	0.52
F	0.03	—	0.01	—	None found	0.01	0.16	—	0.01	—	—
B_2O_3	—	—	not analyzed	—	—	Not analyzed	Not analyzed	—	Not analyzed	—	—
CO_2	—	—	—	—	—	0.05	—	—	0.17	Not analyzed	—
Others	—	—	1.54	—	—	0.52	—	—	1.01	—	—
Total	—	—	99.6	—	100.28	99.48	99.58	—	99,12	—	—
Recomputed, by the A.N. Zavaritskiy method											
a	—	—	10.7	—	14.5	14.0	14.5	—	15.1	13.6	14.1
c	—	—	0.2	—	0,3	0.1	0.3	—	0.1	0,7	0.5
b	—	—	6.3	—	1.5	2.4	2.5	—	4,3	3,5	2.4
s	—	—	82.8	—	83.5	83.5	82.5	—	80.5	82,2	83.0
f'	—	—	2.8	—	28.5	24.3	41.03	—	49.2	32.7	35.1
m'	—	—	5.9	—	14.2	10.8	7,7	—	7.6	9.09	5.4
t'	—	—	0.15	—	0.0	0.08	0,07	—	0.1	0.06	0.8
φ	—	—	7.8	—	14.2	5.4	2.5	—	24.6	14,5	16,2
n	—	—	29.4	—	2.7	14.1	62.1	—	48.2	47.9	52.8
c'	—	—	—	—	—	—	—	—	—	—	—
a'	—	—	81.7	—	57.1	64.8	51.3	—	43.1	58.1	59,5
Q	—	—	45.0	—	37,7	38.6	35.9	—	30.6	36.5	37.3
a/*c*	—	—	40.8	—	48.3	140.0	48.3	—	151,0	19.4	3.2

differences consist in the facts that these granite-porphyries have lower contents of silica (average 74.1% as compared to 76.47% for the average type according to Daly) and calcium oxide (average 0.20% compared to 0.45% for the average type according to Daly) than alaskite and contain iron oxide.

The results of the chemical analyses of the felsites and quartz-porphyries show the close petrochemical compositions of these rocks, and a comparison of these with the granite-porphyries indicates that the latter differ in having a smaller amount of potassium oxide and a greater amount of sodium oxide, as well as a greater content of ferric and ferrous oxide. It should be said that almost all the specimens of felsites, quartz-porphyries and granite-porphyries analyzed contained very small amounts of fluorine (from 0.01 to 0.16%). Only two specimens were analyzed for boron, and 0.01% of B_2O_2 was found in them.

In order to determine the petrochemical properties of the felsites, quartz-porphyries and granite-porphyries, the chemical analyses were recomputed by the A. N. Zavaritskiy method (Table 2), and a graph of the chemical composition was constructed (Figure 6), which shows that the parameters of the given rocks

Table 3

Results of Spectrum Analyses of Felsites

Elements	Specimen									
	4258	4254	4210	4257	4252	4251	4260	4253	5811	5815
Be	1	1	1	1	1	1	1	1	1	1
Sr	2	3	2	2	1	3	—	3	1	2
Ba	4	4	3	3	1	4	—	3	2	2
Zr	2	2	2	2	1	2	2	2	3	2
Y	1	1	2	1	—	1	1	2	—	1
Nb	—	—	—	—	—	—	—	—	2	1
Sc	—	—	—	—	—	—	—	—	—	1
Cu	2	1	3	4	1	1	1	1	2	1
Ga	1	1	1	2	1	2	2	1	1	1
Sn	4	2	2	4	1	2	1	2	2	3
Pb	1	1	—	2	—	1	1	1	2	1
As	—	—	—	—	—	—	—	—	2	—
Mo	—	1	—	—	—	1	1	2	—	1
W	—	—	—	—	—	—	—	—	2	1
Fe	5	5	5	5	4	5	5	5	—	—
Ti	4	4	4	4	2	4	4	4	3	4
Mn	3	3	3	4	3	3	3	3	2	3
V	1	1	1	1	—	1	—	—	1	—
Cr	1	—	—	1	—	—	—	—	1	—
Ni	—	—	1	1	—	—	—	—	—	—

Note: Li, Ta, La, Ce, P, Zn, Ge, Ag, In, T1, Sb, Bi and Co were not found. 1-0,000n; 2-0,00n; 3-0, 0n; 4-0,n; 5-(n); 6-(n+)

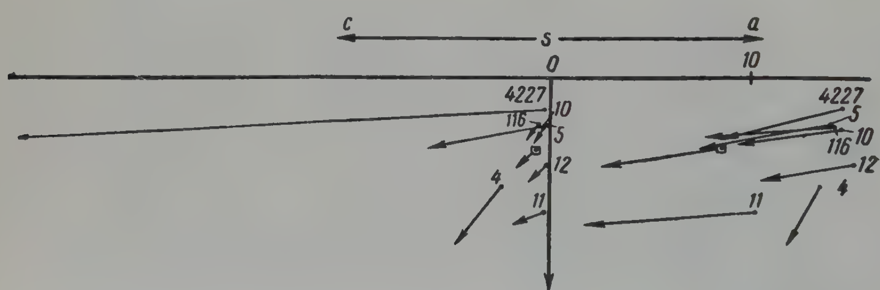

FIGURE 6. Diagram showing the composition of subvolcanic rocks. 11,4227 - felsite; 5 - quartz-porphyry; 10 - 12 - granite-porphyry; 116 - intermediate alaskite, after Daly; 4 - intermediate granite, after Daly; vectors without figures - average composition of Mar'yanovskiy granites.

approach most nearly to Point 116, corresponding to the average type alaskite in Daly's classification. Moreover in all the rocks the c parameter was sharply decreased; this is explained by the presence of small amounts of plagioclase, represented by albite or by albite-oligoclase.

In addition, in the case of the felsites and quartz-porphyries the n parameter is considerably smaller because of the sharp predominance of potassium oxide over sodium oxide. For example, the n parameter in these rocks varies from 2.7% to 29.4%, with an average of 15.5%, as opposed to 52.8% in the average alaskite type according to Daly. The remaining parameters in the rocks described approach the parameters of Daly's average alaskite. An exception is Specimen 11 (felsite), in which the b parameter is increased to 6.3%, as compared to 2.4% for the average alaskite according to Daly. This increase is explained by the presence of tiny chlorite flakes in the felsite.

Comparing the results of chemical analyses

of the felsites, quartz-porphyries and granite-porphyries with the chemical composition of the Mar'yanovskiy granites (Table 2 and Figure 6), we see that the former are distinguished by a sharply increased content of potassium oxide and correspondingly decreased amounts of sodium, calcium and magnesium oxides, as well as ferrous and ferric oxides. Thus the felsites and quartz porphyries described here are more acidic, and contain greater amounts of potassium oxide, than the Mar'yanovskiy granites.

DISTRIBUTION OF THE ACCESSORY ELEMENTS IN THE FELSITES, QUARTZ-PORPHYRIES AND GRANITE-PORPHYRIES

Tables 3, 4 and 5 show that the felsites, quartz-porphyres and granite-porphyries usually contain Ba, Sr, Be, Zr, Y, Sn, Cu, Ga and Pb. In certain areas small amounts of Nb, Ce, La, Sc, Mo, W, V, Cr and Ni have been found. Spectrum analyses made in the All-Union Institute of Mineral Raw Materials (VIMS) have also found Yb in the felsites and quartz-porphyries.

Among all these elements, Be, Zr, Y, Nb, F, Sn, Ga, Pb, Cu and Mo are the leading accessory elements in the felsites, quartz-porphyries and granite-porphyries. These same elements, with the exception of niobium, are usually observed in the chloritized and quartzified sandstones occurring at the contact with the felsites.

Beryllium is constantly present in small amounts (traces) in all the analyzed specimens of felsites, quartz-porphyries and granite-porphyries, as well as in the orthite and zircon of the rocks described (0.000n %).

These rocks also contain zircon in small amounts (0.0n%); the greatest amount of this mineral (n %) was found in the heavy non-electromagnetic fraction of these rocks. These data were confirmed by special studies of the accessory minerals.

Yttrium in small amounts (0.000n, 0.00n %) was usually present in almost all the analyzed specimens. In the electromagnetic fraction of the prepared concentrate of the average felsite sample, its content was 0.00n %, and the greatest amount (0.n %) was found in the orthite of these rocks.

Niobium was found by spectrum analyses only in certain specimens of granite-porphyries (0.000n; 0.00n %) and in the heavy non-electromagnetic fraction of the felsites in the amount of 0.n %. About 1% of niobium was established by X-ray analyses in the cassiterites within the miarolitic cavities in these rocks.

Table 4

Results of Spectrum Analyses of Synthetic Thin Sections of Felsites, by Fractions

Elements	Heavy fraction	Electromagnetic fraction	Magnetic fraction
Be	0.000*n*	—	—
Li	—	—	—
Sr	—	—	—
Ba	—	—	—
Zr	*n*	—	—
Y	—	0.0*n*	—
Nb	0.0*n*—	—	—
Ta	—	—	—
La	—	—	—
Ce	—	—	—
Sc	—	—	—
P	—	—	—
Cu	0.0*n*—	0.*n*	0.00*n*
Zn	—	—	—
Ga	—	0.001	—
Ge	—	—	—
Ag	—	—	—
In	—	—	—
Sn	0.*n*+	0.*n*+	0.0*n*
Tl	—	—	—
Pb	0.0*n*	0.0*n*	—
As	0.*n*	0.*n*	—
Sb	—	—	—
Bi	—	—	—
Mo		0.00*n*	0.00*n*—
W	0.*n*	0.0*n*	
Fe	0.*n*	*n*—	*n*+
Ti	0.*n*+	0.0*n*	0.0*n*+
Mn	0.00*n*+	0.0*n*	0,*n*
V	0.01	0.001	0.00*n*—
Cr	—	0.001	0.0*n*—
Ni	0.00*n*+	—	0.01
Co	—	—	0.001

Lanthanum and cerium in amounts of 0.n % were found only in the orthites taken from the felsites and granite-porphyries.

Fluorine in small amounts—from 0.01 % to 0.16 %—was discovered by chemical analyses in all the analyzed specimens of felsites, quartz-porphyries and granite-porphyries; its maximum content (0.16 %) was observed in the granite-porphyries.

Only three specimens were analyzed for boron, and in two of these B_2O_3 was discovered in quantities of 0.01 %.

Tin in very small amounts (0.00n or 0.000n %) is constantly present in all the analyzed specimens, but its greatest content (0.n %) was discovered in the felsites and granite-porphyries that contained miarolitic cavities

Table 5

Results of Spectrum Analyses of Cassiterites

Intensity of lines	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 1654	Specimen 1672	Specimen 1614
Very strong	W, Sn	W, Sn	Sn	Sn	Sn	Sn	W, Sn
Strong	Fe, Ti	Ti	Fe	Fe, Ti	—	—	Nb
More than average and average	Cu	Fe, Pb, Nb	Cu, W, Ti	Cu, W, V	Fe, Nb, W	Si, Fe, Nb, W	Fe, Ti
Weak	In, Mg, V, Mn	—	—	Sc	Y, Ti	Ti	Si
Very weak	Pb	Mn, Sc, Y, Zr	Ag, Mo, Bi, V, Mn	Mn	Cu, Ca, Be, Zr	Cu, Ca	Sc, Zr, Be
Traces and very slight traces	Be, Ni, Bi, Cr	Cu, Be, Bi, V	In, Sb	Be, In	Pb, V	Be, Pb, Sc, Y, Zr	Cu, Ca, In, V, Y

(Specimens 4258, 4257, 5815). In the prepared concentrates of the felsites the tin content also mounted to 0. n %.

Gallium in small quantities (0.000n, 0.00n %) was constantly present in both the felsites and quartz-porphyries, as well as the granite-porphyries.

Small amounts of copper and lead were also constantly observed in the rocks described here, the copper content sometimes increasing to 0.0n, and in prepared concentrates to 0. n %; the lead content in the latter reached 0.0n %.

Quite often both the felsites and quartz-porphyries and the granite-porphyries showed traces of molybdenum, whose content in prepared concentrates was 0.00n %. Wolfram was also found in the granite porphyries and prepared concentrates of the felsites.

From this review one may conclude that these felsites, quartz-porphyries and granite-porphyries contain relatively large amounts of accessory elements, of which the most important are Be, Zr, Y, Nb, F, Sn, Ga, Pb, Cu and Mo.

RELATIONSHIP OF MINERALIZATION TO THE FELSITES, QUARTZ-PORPHYRIES AND GRANITE-PORPHYRIES

As already observed above, the felsites, quartz-porphyries and granite-porphyries, which in the region under investigation form a small stock, contained a large number of miarolitic cavities filled with druses of quartz (morion in some areas), perthitic microcline and cassiterite. The existence of these cavities, their peculiar structure (micro-poikilitic), the presence of fluorite and tourmaline among the accessory minerals and other signs testify that the magma from which the felsites, quartz-porphyries and granite-porphyries were formed was undoubtedly rich in volatile elements.

One of the chief accessory minerals in the rocks described here, together with zircon, anatase, fluorite, orthite and others, is cassiterite (Table 1), and the chief accessory element in tin (Table 3). The felsites are frequently cut by quartz and quartz-chlorite veinlets containing increased amounts of cassiterite, at whose contacts they are quartzified and chloritized. The known occurrences of tin-ore mineralization in this region are physically closely associated with the felsites and are localized in the sandstones at the contacts with the felsite stock, since the felsites here form a series of very thin injections in the enclosing rocks. The ore bodies are represented chiefly by the quartz-chlorite veinlets with their larger quantity of cassiterite. At the contact with these veinlets, the sandstones are usually quartzified, chloritized and contain cassiterite.

Thus the changes in the enclosing rocks round the felsites are analogous to those observed in host rocks at the contact with ore bodies. The latter differ only in the intensity of the process. Moreover the cassiterite in the felsites is colored lighter shades of brown or pale cinnamon-brown than the cassiterite in the ore bodies, which is dark-brown or dark cinnamon, indicating, as the spectrum analyses show, that it contains a larger amount of iron.

Comparison of the spectrum and the X-ray analyses of the cassiterite in the felsites with that in the ore bodies (Table 5, Specimens 2, 654 and 1, 3 and 4) shows that together with the elements Be, Sc, Bi, and W, common to both the former and the latter, they also possess certain peculiar properties. For example, the cassiterite of the felsites is distinguished from that of the ore bodies by the presence of niobium and yttrium. The presence of niobium suggests, as papers by Ya. D. Gotman (1), Ye. I. Dolomanova and Iv. F. Grigor'yev have pointed out, that the cassiterite in the felsites was formed under higher temperatures than the cassiterite in the quartz-chlorite veins, and this fact in turn indicates that this cassiterite is directly associated with post-magmatic processes in the stock, and was not introduced by later hydrothermal solutions.

In summarizing all that has been said above, we may conclude that the known tin-ore mineralization in this district, localized in the exocontact zone of the felsite stock and directly within it, is genetically associated with these felsites, which are subvolcanic formations.

COMPARISON OF THE PETROCHEMICAL PROPERTIES OF THE FELSITES, QUARTZ-PORPHYRIES AND GRANITE-PORPHYRIES WITH THOSE OF THE MAR'YANOVSKIY GRANITES

It was stated at the beginning of this article that in the region investigated, in addition to the felsites, quartz-porphyries and granite-porphyries, there are also extensive outcrops of Late Cretaceous granites that have been given the name Mar'yanovskiy granites. Direct physical connections between the felsites and these granites have not been observed, since the latter are exposed some 12 km southwest of the felsite outcrops. The Mar'yanovskiy granites have been described in detail in one of the present writer's papers (5), so that here it will merely be noted that these granites are characterized by the presence of a large amount of miarolitic cavities filled with morion and perthitic microcline (Figure 7), and in some areas with tourmaline and cassiterite.

Comparison of the Mar'yanovskiy granites with the felsites, quartz-porphyries and granite-porphyries shows that all these rocks are petrochemically similar. For example, in the felsites and quartz-porphyries, as in the Mar'yanovskiy granites, one observes a high content of alkali, a predominace of potassium oxides over sodium oxides, small amounts of calcium and magnesium oxides and a high content of silica. Moreover in the felsites, as compared to the Mar'yanovskiy granites, there has been established: 1) a higher content of potassium oxide, equal on the average to 6.77%, whereas in the Mar'yanovskiy granites it is 5.24%; 2) a lower content of calcium oxide (0.27%) and magnesium oxide (0.17%), whereas in the Mar'yanovskiy granites the average amount of CaO if 0.73% and of MgO is 0.28%.

Mineralogically the felsites, quartz-porphyries and Mar'yanovskiy granites are also very close to each other; in both the former and the latter, potassium felspar predominates over plagioclase, represented by albite and albite-oligoclase. The most important accessory minerals in both the latter (Table 6) and the former (Table 3) are zircon, orthite, cassiterite, anatase, tourmaline and magnetite. It must be specially stressed that in the felsites, as in the Mar'yanovskiy granites, such rare minerals as naegite and fergusonite have been found, although in quite small amounts. Fluorite, which is a characteristic accessory mineral of the felsites, is usually also present in small amounts in the Mar'yanovskiy granites.

Characteristic accessory elements of the two rocks being compared (5) are Zr, Y, Nb, Sn, Ga, Pb and Cu. Lanthanum, which is usually present in the Mar'yanovskiy granites, is sometimes also noted in the felsites and is, together with cerium, a constant admixture in the orthites of both the felsites and the Mar'yanovskiy granites. Fluorine and molybdenum, which are rather frequently observed in the felsites and quartz porphyries, are encountered somewhat more rarely in the Mar'yanovskiy granites.

Moreover both the rocks compared contain large numbers of miarolitic cavities filled with morion, perthitic microcline and cassiterite. The granite-porphyries in the central part of the felsite stock are very close in composition and structure to the granite porphyries of the peripheral parts of the Mar'yanovskiy granite massif proper.

According to our observations, the Mar'yanovskiy granites were formed under hypabyssal conditions in the presence of a large amount of volatile components. This is indicated by the extensive development in these granites of porphyritic structures, the presence of many miarolitic cavities filled with crystals of perthitic microcline, morion, tourmaline and cassiterite, the presence morion crystals in the groundmass of the granites, and other factors.

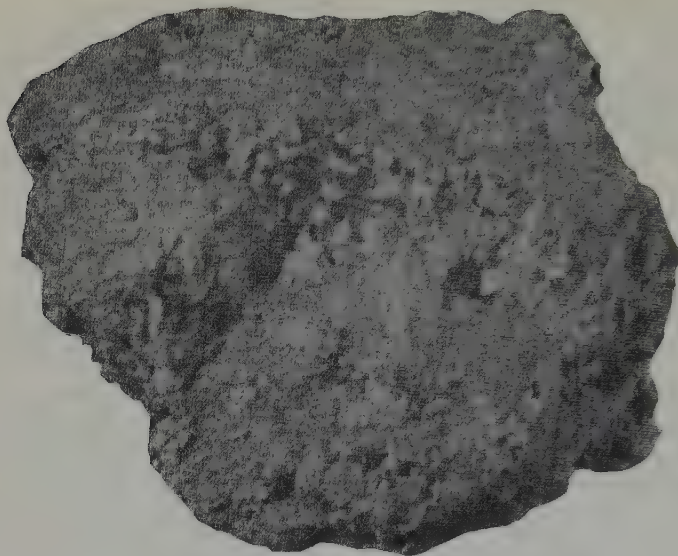

FIGURE 7. Mar'yanovskiy granite with miarolitic cavities. Intermediate composition.

Table 6

Distribution of Heavy Minerals in Various Granites of the Mar'yanskiy Intrusive Complex

Rock	Heavy minerals, encountered:		
	in large amounts	in small amounts	rarely and in very slight amounts
Medium-grained and porphyritic biotite-granites	Zircon, orthite, magnetite	Anatase, tourmaline, ilmenite, fergusonite, martite	Cassiterite, apatite, fluorite, pyrite, brunite, naegite, scheelite, monazite
Fine-grained biotite-granites	Zircon, orthite, magnetite	Cassiterite, anatase,. tourmaline, martite	Fluorite, pyrite, brunite, naegite, basobismuthite, ilmenite, monazite, fergusonite
Pegmatoid granites	Zircon	Cassiterite, orthite, fergusonite	Fluorite, anatase, naegite, scheelite, tourmaline, ilmenite, monazite

The formation of the felsites, quartz-porphyries and granite-porphyries took place in the presence of large amounts of volatile components, as confirmed by the presence of miarolitic cavities filled with morion, perthitic microcline, and cassiterite, by features of their structure, by the presence of fluorite and tourmaline among the accessory minerals, and other indications. Thus all the data cited above show that the Mar'yanovskiy granites and the felsites have a number of petrochemical features in common and are apparently the products of the same magma chamber.

CONCLUSION

All the available data, only part of which have been set forth above, point to the following basic conclusions:

1. During Late Cretaceous times in the region investigated there was an intrusion of tin-bearing granites, which, as in other regions of the Primor'ye, were characterized by an alaskite composition and were rich in potassium oxides.

2. In addition to the earlier described tin-bearing granites, there were also subvolcanic tin-bearing formations representing the results of a continuing evolution of the ore-bearing magma in the direction of its enrichment with potassium oxide and silica.

3. The existence of a common magma chamber for the intrusive and subvolcanic formations is confirmed by the identical mineral compositions, petrochemical properties and the presence of the same elements as admixtures found in both rocks.

4. Within the region investigated a genetic association between the tin-ore mineralization and the subvolcanic rocks has been proved. This association is indicated: by the presence in the felsites of miarolitic cavities containing more high-temperature cassiterite than that which is observed in the later hydrothermal veins, by the close physical connection between the ore bodies and the felsites, and by other characteristics.

It may be remarked in conclusion that within this region similar relationships between tin-ore mineralization and subvolcanic rocks were earlier established by N. N. Vasil'kova and A. G. Teremetskaya, along the upper reaches of the Iman River and in the basin of the Kintsukhe River.

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CHEMICAL INVESTIGATIONS OF FAHLERZ

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In studies of the composition of fahlerz, the problem of isomorphic replacements for non-isomorphic admixtures is solved by mineragraphic investigations of polished sections, under a magnification of 400 - 500 times at most, and by semi-quantitative, but more often qualitative, spectrum analyses. Complete chemical analyses are seldom made because of the small quantity of the material, the difficulty of screening, and the lack of practical interest on account of the small industrial importance of fahlerz, which rarely represents independent accumulations.

The complex composition of fahlerz is not reflected by the Pauling-Belov formula, which was established for pure representatives of the group (tetrahedrite and tennantite); this suggests the possibility that there may be widespread isomorphism in the minerals of this group.

J. H. Bernard (16) has introduced the term "isomineralic elements," by which he means those elements the individual minerals of which, although they may contain these elements, are not discovered by microscope study.

In 1955 - 1957 the present writer made a study of the chemical composition of fahlerz on the basis of chemical analyses of 50 specimens from various deposits in the U.S.S.R. and certain other countries. The data of these chemical analyses were taken from the literature, and from the card catalogue of the Institute of the Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry of the Academy of Sciences of the U.S.S.R. (including 3 analyses made by the present author). The author relied mainly on summaries of the results of chemical analyses of fahlerz set forth in an article by E. M. Kupletskaya, included in a new reference work on mineralogy (E. M. Kupletskaya "Tetrahedrite," in the press). Recalculation according to the Pauling-Belov-$A_{12}B_4C_{13}$ formula in all cases gave detailed coefficients; from this arose the concept of fahlerz as a mixture of different crystalline substances, leading the present author to a more rational method of calculation, specifically: from the data for each chemical analysis was taken the combination of atoms that fitted into the exact Pauling-Belov formula—$(Cu, Fe, Zn, Hg, Ag, Cd)_{12}(As, Sb, Bi)_4S_{13}$—and the remaining free atoms were attributed to the minerals that might be present (on the basis of the mineral associations of the given deposit or of minerals encountered in the given region). It rarely occurred that the remaining atoms had to be tied together into the formula of minerals not usually associated with fahlerz, but theoretically this was fully possible.

In certain individual calculations it became necessary to represent certain elements (silver, copper, sulfur and very rarely antimony, arsenic, and tellurium) as occurring in the native state; it is known that these chalcophilic elements have a strong tendency to occur in isolation, so that they appear in nature as native metals and metalloids.

From the computations of the results of chemical analysis of 50 specimens of fahlerz (Table 1) it was found that:

Present in	22	specimens	chalcocite
"	20	"	galena
"	18	"	chalcopyrite
"	18	"	native sulfur
"	11	"	covellite
"	9	"	arsenopyrite
"	7	"	horsfordite (Cu_6Sb)
"	7	"	native copper
"	6	"	native antimony
"	4	"	native silver
"	2	"	antimonite
"	2	"	nickelite
"	2	"	realgar
"	1	specimen	orpiment
"	1	"	germanite
"	1	"	loellingite
"	1	"	native arsenic
"	1	"	petzite
"	1	"	native tellurium
"	1	"	tellurobismuthite
"	1	"	zinkenite

[1] O khimicheskikh issledovaniyakh bleklykh rud

Table 1

Chemical Analyses of Minerals in the Fahlerz Group of Ores, % Weight

Elements	Tetrahedrites								
	1	2	3	4	5	6	7	8	9
Cu	45.12	37.48	45.39	37.70	37.02	36.56	39.55	37.75	30.56
Zn	—	6.50	—	3.87	2.80	—	1.93	6.51	traces
Fe	8.34	1.10	1.32	5.13	2.34	1.19	3.78	1.10	3.51
Ag	0.17	—	—	traces	2.92	—	0.10	0.11	16.26
Hg	—	—	—	—	—	12.65	—	—	—
Pb	—	0.21	0.11	—	traces	—	—	0.71	0.05
Sb	21.61	28.77	28.85	26.81	29.22	26.70	29.42	28.66	27.73
As	traces	traces	traces	traces	—	—	0.06	—	traces
S	23.81	25.06	24.48	26.49	24.88	22.49	24.94	24.61	23.15
Total	99.05	99.12	100.15	100.00	99.18	99.59	99.78	99.98	100.26
Analyst or author and year	Antipov, 1915	V. M. Sender-ova, 1955	G. T. Prior, 1900	Shannon, 1926		V. Pakozdy, 1949		A. Kretschmer, 1911	G. T. Prior, 1900

Elements	Tennantites								
	1	2	3	4	5	6	7	8	9
Cu	53.36	49.83	42.03	44.53	35.72	42.92	40.0	46.03	39.76
Zn	0.23	—	7.76	7.28	6.90	4.49	7.80	—	6.24
Fe	1.58	1.11	0.62	0.62	0.42	0.53	4.5	3.37	2.20
Ag	—	1.87	1.24	0.02	13.65	—	—	—	—
Hg	—	—	—	—	—	—	—	—	—
Pb	—	0.17	—	0.35	0.86	—	—	—	—
St	—	—	—	traces	0.13	1.36	1.40	1.47	1.90
As	18.33	19.04	19.80	18.77	17.18	22.41	18.10	19.85	19.18
S	26.60	27.60	28.08	27.60	25.04	28.55	28.0	29.24	27.82
Total	100.10	99.62	99.53	99.37	99.90	100.26	99.80	100.00	97.10
Analyst or author and year	A. Kretschmer	G. T. Prior, 1900	G. T. Prior, 1916	F. W. Kriesel, 1924	S. L. Penfield, 1892	M.M. Stukalova 1952	A. V. Sikney, 1915	Yu.S. Nesterova 1940	T. N. Shadlun, 1940

Table 1 continued

Chemical Analyses of Minerals in the Fahlerz Group of Ores, % Weight

Elements	Tennantites 10	Tennantites 11		Mixed fahlerz 1	2	3	4	5
Cu	41.17	42.76		29.99	34.17	39.41	18.20	30.04
Zn	5.25	6,28		2.49	—	3.79	3.62	0,59
Fe	2.66	2,07		3.29	—	4.47	5.35	9.83
Ag	—	—		12.74	0.18	1,60	26.63	—
Hg	—	—		—	—	—	—	—
Pb	—	—		0.25	—	—	0.44	0.26
Sb	5.03	5,20		26.42	19.65	24,90	21,35	28,82
As	18.47	15,98		0.58	0.69	1,18	1.21	1,50
S	28.17	27,71		23.71	21.97	24.59	23.10	24.48
Total	100.75	100,00		99.47	101.57	99.94	99.90	98.98
Analyst or author and year	V.M. Senderova, 1940	V.M. Senderova, 1940		A. Kretschmer, 1911	R.M. Thompson, 1946	Yu.N. Knipovich, 1940	Williams —	E. Manasse, 1906

Mixed fahlerz

Elements	6	7	8	9	10	11	12	13	14
Cu	18.05	41.29	39.54	36,57	27.54	40.80	39.20	28.97	31.74
Zn	3.06	3,42	4.92	0,05	2.92	5.10	5.21	8.11	9,33
Fe	6,76	3,37	2,02	4,76	4.98	2.94	2.55	6.17	3.45
Ag	25,53	—	traces	3.25	0.11	—	—	5.45	3.81
Hg	—	—	—	traces	—	—	0.09	—	—
Pb	0.44	—	—	—	8.66	—	—	1.60	4.26
Sb	21.43	23.92	25.96	30.21	23.78	21.59	24.48	21.86	18.76
As	1.57	1,63	1,70	1,80	1.90	2.43	2.59	2.84	3.34
S	23.11	25.28	24,71	24.02	30.27	26.25	24.18	24.23	23.83
Total	99.95	98.91	99,21	100.66	100.16	99 11	98.30	99.23	98.52
Analyst or author and year	Williams —	S.A. Yushko, 1948	Mamontov, 1915	Ye.K. Lazarenko, 1941	Yu.N. Knipovich, 1940	Loewe, 1940	S.A. Yushko, 1948	Iossa, 1915	Mamontov, 1915

Mixed fahlerz

Elements	15	16	17	18	19	20	21	22	23
Cu	30.46	33.39	38.16	40.88	35.54	44.01	33.83	37.66	46.54
Zn	3,86	5.33	4.82	1.62	3,31	3.13	—	7.25	2.68
Fe	6.60	2.67	3.07	4.56	3.86	4.69	6.40	0.42	2.62

Ag	1.82	1.71	traces	0.03	6.20	0.02	1.37	0.33	5.85
Hg	—	0.75	—	1.53	—	0.42	—	—	—
Pb	—	0.83	1.47	—	—	—	—	—	3.60
Sb	18.65	23.50	19.78	20.76	20.38	21.12	14.72	20.05	9.67
As	4.18	4.49	5.02	5.11	5.54	5.65	6.98	7.22	7.70
S	23.69	23.89	24.92	25.40	25.63	20.95	26.40	27.14	22.19
Total	89.26	99.06	97.24	99.94	100.46	100.00	98.46	100.37	100.85
Analyst or author and year	O.A. Alekseyeva, 1953	A. Kretschmer, 1911	Yu.N. Knipovich, 1930	V. Pakozdy, 1949	P. P. Pilipenko, 1915	I. Nazmi-Azer, 1957	Hilger, 1865	O.A. Alekseyeva, 1950	Antipov, 1915

Mixed fahlerz

Elements	24	25	26	27	28	29	30	31	32
Cu	43.97	49.01	40.91	28.82	35.72	41.82	35.12	42.05	41.65
Zn	2.90	—	4.85	4.90	—	4.51	8.52	6.09	2.33
Fe	4.84	0.87	2.57	1.69	6.51	4.39	2.66	1.48	4.11
Ag	—	0.63	0.23	—	0.04	0.13	—	0.04	—
Hg	—	—	0.80	—	—	—	—	—	—
Pb	—	—	—	28.81	—	0.24	2.06	—	—
Sb	12.81	12.56	15.77	1.69	2.19	9.71	12.57	10.87	20.04
As	8.37	8.79	9.03	9.34	11.44	12.20	12.51	12.57	13.68
S	25.48	27.06	26.34	23.23	29.10	27.00	26.56	27.12	17.98
Total	98.37	98.92	100.50	98.48	99.27	100.00	100.00	100.22	99.79
Analyst or author and year	Yu.N. Knipovich, 1940	Antipov, 1915	A. Kretschmer, 1911	Yu.S. Nesterova, 1956	Brauns, 1870	Yu.S. Nesterova, 1955	Williams, 1951	A. Kretschmer, 1911	E. Dittler, 1942

Note: The analyses cited also indicate the following elements:
Tetrahedrites: Bi No. 8 - 0.53%. Tennantites: Co. No. 8 - 0.04%; Se No. 4 - 0.06% and Ge No. 4 - 0.14%. Mixed fahlerz: Bi No. 2 - 7.05%, No. 20 - 0.01%, No. 21 - 4.55%, No. 28 - 13.07%, C No. 8 - 0.23%, No. 21 - 4.21%, No 28 - 1.20%. Ni No. 5 - 3.46%, No. 16 - 2.50%, No. 21 - traces Se No. 8 - 0.13%, Te No. 2 - 17.34%, No. 22 - 0.10%.

The SiO_2, MgO and CaO indicated by many analyses have been eliminated from the analytical data and appropriate corrections made in the remaining determinations.

The mineral specimens analyzed were taken from the following deposits:
Tetrahedrites: 1 - Altay, Zyryanovskoye; 2 - Kazakhstan, Kara-Oba; 3 - France, Bord d'Oison; 4 - USA, Idaho, Gipotik; 5 - Rumania, Kisban'ya; 6 - Czechoslovakia, Al'sosaya; 7 - Czechoslovakia, Dobsina; 8 - Rhine region, Horhausen; 9 - Germany, Baden, Wohlfach.
Tennantites: 1 - England, Cornwall; 2,3 - Switzerland, Binnenthal; 4 - Southwest Africa, Tsumeb; 5 - Colorado, Molly Gibson; 6 - Caucasus; 7 - Urals, Kyshtymskoye; 8 - Kazakhstan, Dzhezkazgan; 9 - Southern Urals, Yulalinskoye; 10 - Kazakhstan, Uspenskoye; 11 - Kazakhstan, Aleksandrovskoye.
Mixed Fahlerz: 1 - Bolivia, Huanchaca; 2 - Nevada, Goldfield; 3 - Eastern Transbaykal, Klichkinskoye; 4,6 - British Columia, Highland Bell; 5 - Italy, Frigido; 7,9,12 - Ukraine, Nagol'nyy Ridge; 8 - Altay, Bezymyannoye; 10 - Eastern Transbaykal, Algachinskoye; 11,24 - Urals, Berezovskoye; 13,14,19, 23,25 - Altay, Zyryanovskoye; 15,27 - Central Asia; 16 - Ziegerland, Muesen; 17 - Transbaykal, Darasunskoye; 18 - Czechoslovakia, Etyosbanya; 20,32 - Styria, Feitsch; 21 - Westphalia, Freidenstadt; 22 - Eastern Siberia, Dzhidinskoye; 26 - Tyrol, Gross-Kogel; 28 - Kremnitz; 29 - Central Asia, Karamazar; 30 - Western Canada, British Columbia, Windfall; 31 - Chile, San Lorenzo, Santiago.

Table 2

Minerals Present as Admixtures in Fahlerz as Revealed by Computation of Data from Chemical Analyses

Type of Fahlerz	Tetrahedrite									Tennantite																	
Analysis No.	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7
Chalcocite	X									X	X		X	X		X				X	X		X	X		X	X
Galena		X	X					X	X		X		X	X							X			X	X	X	
Chalcopyrite	X			X								X	X			X				X	X			X		X	X
Native sulfur		X		X	X							X					X	X	X			X			X		
Covellite										X	X						X	X	X								
Arsenopyrite							X			X							X	X	X								
Horsfordite			X				X	X	X																		
Native copper			X			X																					
Native antimony							X	X	X																		
Native silver														X									X				
Antimonite					X																						
Nickelite																									X		
Realgar															X												
Orpiment																											
Germanite													X														
Loellingite																											
Native arsenic															X												
Petzite																						X					
Native tellurium																						X					
Tellurobismuthite																						X					
Zinkenite																											

Table 2 shows the number of chemical analysis and the mineral admixtures that appeared through computation.

From the experience of mineralogy it is known that the usual and most common inclusions in fahlerz are galena, arsenopyrite and chalcopyrite. The calculations, however, revealed that frequent admixtures in fahlerz, in addition to chalcopyrite and galena, are chalcosite, native sulfur and covellite, and that native copper, horsfordite, native antimony and native silver are frequently encountered.

The theoretical possibility of such inclusions in fahlerz may be proved by considering the paragenesis of the minerals in the four-(or more) component system Fe-As(Sb)-Cu-S. When the results of these recomputations of chemical analyses in terms of mineral admixtures are compared to the A. G. Betekhtin graph given above, it will be seen that the most frequent and typical inclusions in fahlerz, discovered by recomputation of these analyses, are at the same time accessories of fahlerz and components of one general system. On the subject of domeykite (Cu_3As), A. G. Betekhtin (3) observes that although this mineral is not encountered in association with fahlerz in nature, it may nevertheless be found, inasmuch as domeykite is one of the possible minerals accompanying fahlerz in its formation under "sulfur-less" conditions.

The present writer's calculations revealed a mineral of a similar type—horsfordite (Cu_3Sb)—which in nature is encountered as independent accumulations in one place, in Asia Minor (Angora, near Mytilene). Recomputation of the corresponding analyses showed that the horsfordite was accompanied by native antimony, native copper and chalcosite—that is, they were formed under "low-sulfur" or "sulfur-less" conditions.

The presence of a certain amount of excess sulfur may possibly be due (according to the

Table 2 Continued

Mixed fahlerz																									Number of samples	Mineral admixtures in molecules per 1 molecule $A_{12}B_4C_{13}$
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32		
×				×	×	×			×						×	×		×	×		×				22	$8\cdot10^{-2}$—$366\cdot10^{-2}$
		×			×	×		×	×						×				×		×	×			20	$5\cdot10^{-3}$— $41\cdot10^{-1}$
×			×			×	×		×		×								×		×				18	$4\cdot10^{-2}$— $88\cdot10^{-2}$
		×	×				×				×		×	×			×					×	×		18	$9\cdot10^{-4}$— $63\cdot10^{-2}$
			×										×			×	×		×				×		11	$14\cdot10^{-3}$—$126\cdot10^{-2}$
×	×		×														×								9	$1\cdot10^{-2}$—$111\cdot10^{-2}$
				×								×												×	7	$6\cdot10^{-3}$— $93\cdot10^{-}$
				×						×					×			×		×					7	$2\cdot10^{-2}$—237.10^{-}
	×											×												×	6	$2\cdot10^{-2}$—$288\cdot10^{-2}$
								×							×										4	$13\cdot10^{-2}$—$119\cdot10^{-2}$
	×																								2	$7\cdot10^{-2}$— $1\cdot10^{-2}$
								×																	2	$46\cdot10^{-2}$—$289\cdot10^{-2}$
																						×			2	$86\cdot10^{-2}$— $44\cdot10^{-2}$
														×											1	$19\cdot10^{-2}$
																									1	$3\cdot10^{-2}$
																								×	1	$12\cdot10^{-2}$
																									1	$8\cdot10^{-2}$
																									1	$2\cdot10^{-2}$
																									1	$214\cdot10^{-2}$
																									1	$28\cdot10^{-2}$
		×																							1	$5\cdot10^{-2}$

concepts of N. V. Belov) to the fact that the interstices or gaps ("phonaryakh") in the fahlerz structure contained not single atoms (S), but double atoms of sulfur (S_2).

In general, it must be said that the literature contains indications that part of the sulfur atoms in certain simple sulfides (for example, pyrite) occur in electrically neutral form—that is, as free atoms. The suggestion has also been made in regard to fahlerz (18) that all three sulfur atoms are electrically neutral in the Cu_3SbS_3 molecule, in which the three atoms of monovalent copper are positively charged and the single atom of tervalent antimony is negatively charged.

The structure of fahlerz, according to N. V. Belov's investigations (1), must be considered analogous to the structure of sodalite. In this case we have a three-dimensional lattice of Cu and S atoms; within it are large gaps, each of which contains the large complex anion $(AsS_3)^{3-}$. Thus the basis of fahlerz must be chalcosite; then the structure of tetrahedrite may be considered as a chalcosite lattice in which gaps have been formed similar to those in the structure of sodalite.

If such gaps extend throughout the volume of the chalcosite, a monomineral is formed whose chemical composition is expressed by the formula $A_{12}B_4C_{13}$ (compare Analysis 2 in Tables 1—tetrahedrite—and 2). If the gaps do not occupy the entire volume of the monomineral, but only some volume greater or less than half of it, we shall be dealing with a solid solution of chalcosite in tetrahedrite.

An example of this may be seen in the fahlerz of the Zyryanovskoye deposit of the Altay. P. P. Pilipenko (11) distinguishes light, dark and intermediate varieties of fahlerz, and recomputation of the data from chemical analysis accordingly give varying contents of chalcosite ranging from 3.66 - 1.33 molecules.

It may further be suggested that in the

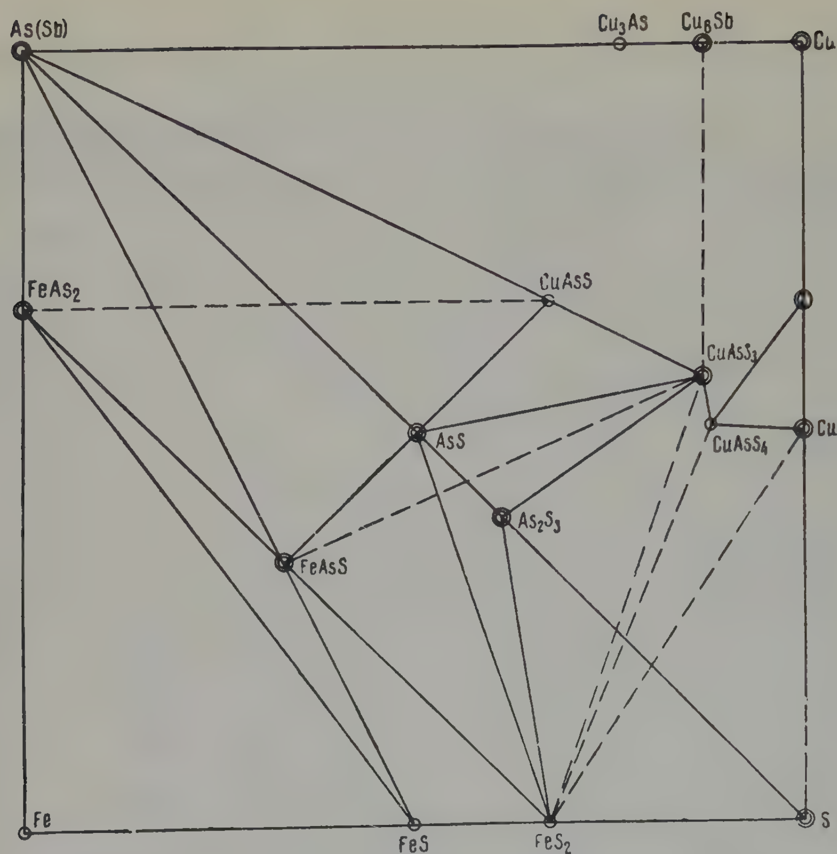

FIGURE 1. Composition-paragenesis of the minerals in the Fe-As(Sb)-Cu-S system, after A. G. Betekhtin (3).

crystallization process in the multicomponent system Fe—As(Sb)—Cu(Ag)—S, along with the fahlerz, there may be formed: 1) chemical compounds of simpler composition (Cu_6Sb, Cu_2S, SuS, Sb_2S_3, AsS, As_2S_3) and 2) the chalcophilic elements (Cu, Ag, As, Sb), and sulfur in the independent atomic state, toward which they tend because of their great ionization potentials.

All these chemical compounds are occasionally observed or may be observed under natural conditions as associates of fahlerz, since they are the products of the same multicomponent system whose crystallization results in the appearance of fahlerz.

The A. G. Betekhtin graph accompanying this article shows the points designating the compositions of minerals forming a paragenetic series in the four-component system. The mineral admixtures in fahlerz discovered by this writer's computations are surrounded by a double circle—these are horsfordite, native copper, chalcosite, covellite, native sulfur, realgar, orpiment, native arsenic, arsenopyrite and loellingite.

The chalcosite included in the fahlerz must be considered as primary, since it was formed at the same time as the fahlerz, is a member of the same paragenetic series and is observed in nature, although very rarely, as a primary mineral. For example, V. Pakozdy (24) has observed, under high magnification, several grains of primary chalcosite in tetrahedrite from Dobšina (Czechoslovakia), and T. N. Shadlun (1952) has found primary chalcosite as inclusions in galena from Kan-i-Mansur, Central Asia; the literature contains a number of other similar communications on this subject.

The covellite found by recomputation of the data from the chemical analyses may possibly be an indication of the beginning of secondary alteration of the fahlerz, sometimes outwardly expressed by a slight tinge of "iridescence" or "fading".

Inclusions of petzite, loellingite, tellurobismuthite, native tellurium, orpiment, realgar, native arsenic and nickel were found in individual cases, in specimens from deposits whose mineral associations were not entirely normal.

If the deposits are classified by groups according to the type of mineral admixtures in the fahlerz, several kinds of deposits will appear. (Chalcopyrite, arsenopyrite, galena and loellingite are not taken into account in classifying the deposits by groups). Examination of the data cited below and comparison of these groups of deposits will show that in some cases the fahlerz of one and the same deposit may belong to different fractions of the hydrotherm, or may have been formed under different physicochemical conditions: for example, the fahlerz of the Altay, the Nagol'niy Kryazh, Switzerland, etc. On the other hand, the fahlerz in British Columbia, in the Highland Bell deposit (Canada), belongs to one generation. The fahlerz of Czechoslovakia, the Rhine basin, Westphalia (Wohlfach), Styria and the Tyrol, according to the type of mineral admixtures, fall into one group and were consequently formed under similar physicochemical conditions.

The antimonite, native sulfur, copper, silver, antimony, arsenic and tellurium revealed by the recomputation may be indications of the small depth of formation of the fahlerz.

In studying the material composition and conditions of formation of deposits, the investigator, along with geologic data, may be able to use conclusions that he might draw from a careful study of the results of chemical analyses of the minerals accompanying the deposit. The strongest argument against the possibility of the existence of such computed mineral admixtures is the fact that such minerals are not seen in polished sections under the usual magnification. It appears to this writer, however, that in certain cases this argument may be overthrown in the future, when mineragraphic investigations with the electron microscope become an everyday matter; then, probably, it will be possible to see submicroscopic inclusions of such minerals in fahlerz, representing isolated individual chemical compounds of chalcophilic elements with sulfur, or monatomic chalcophilic elements. In a recent paper it is stated (7) that the heterogeneity of the grains in a solid solution of the two-component alloys Al—Cu and Al—Ti could be seen in polished sections only in a "dark field", illuminated only by the marginal rays from the light source. The authors (7) describe their method of "dark-field" microscope investigations, which allowed them to discover the presence of ultramicrocrystals in crystals of a solid solution that appeared to be "absolutely homogeneous" under direct reflected light, even at magnifications of x 1000.

1. Deposits whose fahlerz was formed under "high-sulfur" conditions, with a fairly oxidation potential are:

Covellite with native sulfur:
Urals, Berezovskoye
Southern Urals, Yulalinskoye
Kazakhstan, Dzhezkazgan
Kazakhstan, Uspenskoye
Westphalia, Freidenstadt

Orpiment with native sulfur:
Western Transbaykal, Dzhidinskoye

Nickelite with native sulfur:
Italy, Frigido

Antimonite with native sulfur:
Rumania, Kisban'ya

Native sulfur:
Eastern Transbaykal, Algachinskoye
Altay, Zyryanovskoye
Kazakhstan, Kara Oba
Central Asia
Chile, San Lorenzo, Santiago
USA, Idaho, Gipotik (?)
Switzerland, Binnenthal

Realgar with native sulfur:
Eastern Canada, Taylor Windfall

Petzite, tellurobismuthite and native tellurium with native sulfur:
USA, Nevada, Goldfield

2. Deposits whose fahlerz was formed under "low-sulfur" conditions, with an insufficiently high oxidation potential:

Covellite and chalcocite:
Central Asia, Chatkal Range
England, Cornwall, Cook's Kitchen
Switzerland, Binnenthal
Urals, Berezovskoye

Chalcocite:
Altay, Bogoyavlenskoye (Bezymyannoye)
Altay, Zyryanovskoye
Transbaykal, Darasunskoye
Urals, Kyshtymskoye
Kazakhstan, Aleksandrovskoye
Central Asia, Lashkerek
U.S.S.R. (Ukraine), Nagol'nyy Ridge
Canada, British Columbia
Highland Bell, British Columbia
Southwest Africa, Tsumeb
Bolivia, Huanchaca

3. Deposits whose fahlerz was formed under "sulfur-less" conditions, with a high reduction potential:

Chalcocite, horsfordite and native copper:
U.S.S.R. (Ukraine), Nagol'nyy Ridge

Horsfordite with native antimony:
Czechoslovakia, Dobšina
Rhine region, Horhausen
Westphalia, Wohlfach
Styria, Feitsch

Horsfordite with native copper:
France, Bord d'Oison

Antimonite with native antimony:
U.S.S.R. (Ukraine), Nagol'nyy Ridge

Chalcocite with native copper (silver):
Altay, Zyryanovskoye
Eastern Transbaykal, Klichkinskoye
Tyrol, Gross-Kogel
USA, Colorado, Molly Gibson

Native copper:
Czechoslovakia, Al'sosaya
Czechoslovakia, Etyosbanya
Westphalia, Kremnitz

Realgar with native arsenic:
Caucasus, enargite deposit

Nickelite with native silver:
Westphalia, Muesen

In cases when, according to computations, the mineral accompanying the fahlerz appears to be on the order of 0.5 - 3.5 molecules per 1 molecule of fahlerz, there is the possibility that this is a solid solution, whose material appears microscopically to be homogeneous.

Since the purpose of this article is a study of the chemical composition of simple (galena and sphalerite) and complex (fahlerz) sulfides, computation of the mineral admixtures, discovery of the nature of the mineral admixtures for each host sulfide, and a comparison of the nature of such admixtures in various regions of the Soviet Union, the author has not deemed it necessary to enter into the question of whether these mineral admixtures are the result of decomposition of the solid solutions, of intergrowths or of various types of inclusions.

There is not sufficient basis for assigning the individual elements to isomorphic replacements of the main components in the sulfides in general, and in fahlerz in particular, on the basis of a single factor (the corresponding magnitude of the atomic radius). It is well known that tetrahedrites, tennantites and fahlerz of mixed type and most varied composition have identical lattices. The accompanying mineral admixtures are not reflected in the structure of the lattice framework, but they may create a certain stress because of their disproportion. Such a structural stress may lead ultimately to the appearance of clear second phases, which are separated out of the solid solutions; such are the emulsions and submicroscopic inclusions of chalcopyrite, the minerals of indium, germanium, gallium, metallic gold, silver, etc.

For this reason the deviation of the chemical composition of fahlerz from the theoretical composition of the formula $A_{12}B_4C_{13}$ should rather be attributed to mineral admixtures than to manifestations of isomorphism The chemical composition of "pure specimens", such as the tetrahedrite from Kara-Oba (with a negligible admixture of galena and a negligible excess of sulfur) agrees quite closely with the formula $A_{12}B_4C_{13}$.

CONCLUSIONS

On the basis of a recomputation of 50 chemical analyses of fahlerz deposits in the U.S.S.R. and certain other countries for the mineral components in the fahlerz, it appeared that the most frequent and specific inclusions are the primary minerals: chalcosite, native sulfur, copper, silver, horsfordite and, among the secondary minerals, covellite.

The possibility of such inclusions is thus far confirmed either by the natural associations of the minerals in the corresponding deposit, or by the physicochemical conditions of formation of the deposit (small depth and consequently low temperature of formation of the fahlerz and its accessories) and is based on the theoretical conclusions of A. G. Betekhtin from a consideration of the composition-paragenesis of typical fahlerz associations in the crystallization of the four-component system Fe—S—Cu—As(Sb).

It was suggested that in certain cases the fahlerz may be considered to be solid solution of chalcosite in tetrahedrite (as in the fahlerz of the Zyryanovskoye deposit in the Altay).

The computations of these analyses do not confirm the possibility of the replacement of sulfur by arsenic and antimony, of arsenic (antimony) by tellurium, although the literature contains such suggestions (16). According to the computations, the tellurium belongs to an independent mineral (tellurobismuthnite) and a small portion of it to free atomic tellurium.

The present article is part of a paper on the study of the chemical composition of galena, sphalerite and fahlerz, the chief purpose of the author being to produce some arguments in favor of a more careful consideration of the data from chemical analyses.

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BRIEF COMMUNICATIONS

MODE OF OCCURRENCE OF THE BAJOCIAN DEPOSITS IN THE NORTHWESTERN CAUCASUS [1]

by R. S. Bezborodov, Ye. A. Gofman and V. G. Rikhter

The Post-Hercynian history of the Caucasus has attracted the attention of many outstanding geologists and has thus been repeatedly and fully discussed. In a large number of cases, because of the thorough knowledge of the Caucasus, this region has been a reference point in the solution of many extremely important problems, such as the analysis of thicknesses and facies, the development of the theory of geosynclines and a number of problems associated with the genesis of minerals, igneous activity, the stratigraphy of Mesozoic and Cenozoic deposits and so forth.

In the pages of geological literature one can find repeated discussions of the existence of definite phases of folding within the Northwestern Caucasus. Particular attention has been paid to the Jurassic phases, and also to the Early Alpine phases in the orogenic cycle. These phases of folding have occupied a prominent place in many general and particular works by many investigators of the Caucasus. The opinion of most geologists is that the most intensive phases of folding were the pre-Toarcian, the pre-Upper Aalenian and the pre-Callovian, of which the pre-Callovian has attracted particular attention, since after this the tectonic plan of the region was essentially changed, and the succeeding deposits formed a new structural stage.

The pre-Callovian phase of folding within the Northwestern Caucasus was marked by intensive movements, as a result of which the Lower and Middle Jurassic deposits were crumpled into a complex system of anticlinal and synclinal structures, differing from the systems of the Paleozoic and Upper Mesozoic structural stages. In one of his papers A. P. Gerasimov [5] suggested calling the pre-Upper Jurassic phase of folding the "Adygey" phase, but this term did not attract adherence, and the phase is most often called pre-Callovian.

In the geological literature no less attention has been devoted to the pre-Upper Aalenian tectonic movements, reflected within the Caucasus in the stratigraphic gap between the Lower and Upper Aalenian, in the truncated thicknesses of these deposits, and in the presence of local unconformities. Nevertheless it must be noted that these movements introduced no essential changes in the structural plan of the Western Caucasus, although manifestations of them are encountered in many places.

In recent years a quite considerable amount of factual data have been accumulated, suggesting that in the Northern Caucasus there were rather intensive tectonic movements at the boundary between the Upper Aalenian and the Bajocian stages. These materials, obtained both from field investigation and from computations of the results of drilling, now make it possible to speak quite reliably about the existence of major tectonic movements in pre-Bajocian times, which apparently characterize the beginning and the first manifestations of the Adygey phase of folding.

The notion of the existence of a stratigraphic gap and of the unconformable mode of occurrence of the Bajocian deposits is not a new one. On the geologic map of the West Caucasus compiled by I. I. Nikshich and other geologists, and also on a number of maps by W. N. Robinson, the Bajocian deposits are shown as lying transgressively upon the underlying rocks. Papers by V. Ye. Khain and L. N. Leont'yev [7, 8, 9], O. S. Vyalov [4] and other investigators also contain conceptions of the occurrence of considerable tectonic movements in pre-Bajocian times. Their analysis of the paleogeography of the Caucasus in Early and Middle Jurassic times enabled V. Ye. Khain and L. N. Leont'yev to assert that since Bajocian times, this region has contained stable areas of uplift which can be traced in a number of places.

The presence of a stratigraphic gap at the boundary between the Upper Aalenian and the Bajocian is also indicated by data set forth in articles by I. R. Kakhadze [6], S. G. Bukiya [2] and others.

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[1] Usloviya zaleganiya bayosskikh otlozheniy v predelakh severo-zapadnogo kavkaza.

It must be noted, however, that the study of the Bajocian deposits in the Western Caucasus is complicated in many respects because they occur at the base of cliffs composed of limestones of Oxfordian and Kimmeridgian age, and in the majority of cases are hidden beneath thick screes composed of fragments of these limestones. For this reason outcrops of Bajocian deposits are very few, and visible contacts between these and the underlying rocks are extremely rare.

In the interstream divide between the Kuban and the Laba Rivers, at the base of the Bajocian stage, there is a clearly discernible stratum of crinoidal limestones, which some investigators, (N. A. Ansberg, Ye. Ye. Migacheva and others) have considered to be Upper Aalenian. In the basin of the Bol'shaya Laba River these crinoidal, highly sandy limestones facies are replaced by peculiar light-greenish-gray sandstones of quartz-felspar composition and abundant flakes of biotite. In the more western districts these were exposed by columnar drilling in the sections of the Malaya Laba and Khodza Rivers, and also in the deep exploratory drill holes in the Barakayevskoye oil and gas deposit (IV producing stratum). Careful studies of the facies of the stratum of crinoidal sandy limestones and the nature of its contact with the underlying deposits, as well as the discovery of fauna in a number of sections of this region, have led the present writers to conclude that the crinoidal limestones lie transgressively upon underlying formations of various ages, from Later Aalenian to Middle Liassic inclusive. The stratum of crinoidal limestones itself is the basal stratum of the Bajocian stage not only in the Kuban region, as shown by I. R. Kakhadze [6], but also over a much greater territory.

Everywhere at the base of the group of crinoidal and sandy limestones there is a layer 0. 3 - 0. 7 m thick, representing a gap, and composed of red oolitic hematite. The oolitic rock contains quite numerous fragments of gastropod and ammonite shells, fragments of belemnites and a considerable number of irregular concentric iron concretions and pebbles of ferruginous rocks. The underlying argillites are usually stained with iron oxide, jarositized and resemble a weathered crust. Higher up in the section the limestones grade into gray argillites, showing no indications of unconformity or interruption in sedimentation.

In the outcrops along the left bank of the Kuban River, somewhat above the village of Krasnogorka, the deposits of Bajocian age, characterized by their ammonite fauna, lie with a sharp unconformity upon the sand and clay series of the Pliensbachian stage. The numerous occurrences of Parkinsonia parkinsoni Sowerby leave no room for doubt that above the Pliensbachian sandstones lies a thick series of deposits of the Bajocian stage, as already pointed out by many geologists working in this region.

In the section along the Bol'shoy Zelenchuk River, near the village of Nizhnyaya Yermolovka (to the north) and in the immediate vicinity (2 - 3 m) below the base of the transgressive stratum of crinoidal limestones, in the argillaceous siltstones and argillites containing chamoisite oolites, the present writer has found numerous (several score) specimens of Leioceras opalinum Rein, Hammatoceras alleoni Dum. and H. fallax Benecke (identified by G. Ya. Krymgol'ts). Several meters above the crinoidal limestones, still within the argillites, V. G. Khel'kvist has found Stephanoceras nadosum Quenst. and St. cf. macrum Quenst. Still higher in the section, some 50 - 70 m above the limestones, the present writer has found numerous shells of Parkinsonia parkinsoni Sow. and Park. sp. Farther west, at the bridge across the River Urup near the village of Pregradnaya, in argillites and siltstones containing chamoisite oolites, analogous to the rocks of the Zelenchuk section, directly beneath the stratigraphic gap, have been found Pleidellia sp., Pl. aalensis Zeit., Hammatoceras cf. insigne Schuebl., H. fallax Benecke, H. sieboldi Opp., Phylloceras cf. heterophyllum Sow. and Leioceras subcostosum Buckm. (identified by G. Ya. Krymgol'ts). In the limestones themselves many ammonites have been found, some of which N. V. Beznosov has identified as Eurystomyceras sp. and others that G. Ya. Krymgol'ts has identified as Otoites sp. Thus the transgressive stratum of limestones in the section along the River Urup is of Lower Bajocian age. In the argillites above the crinoidal limestones (some 30 - 40 m) and higher, the present writer has encountered Parkinsonia sp., Parkinsonia parkinsoni Sow. and P. orbigniana Wetz.

Near the village of Krugloye, on the interstream area between the Urup and Bol'shaya Laba Rivers, about 10 m below the crinoidal stratum in the section, there were occurrences of Leioceras opalinum Rein. and Gallyphylloceras connecteus Litt. From the same level, in the argillites directly beneath the cornice of the crinoidal limestones, D. I. Vydrin cites occurrences of Pleidellia cf. aalensis Zeit., Grammoceras cf. fluinans Dum. and Leioceras costosum Quenst. About 10 - 15 m above the transgressive bed he has found Perisphinetes tenuissima Seim. and fragments of Parkinsonia ex gr. parkinsoni Sow. In the lower part of the crinoidal limestones the present writer has found two well-preserved belemnite rostra, which G. Ya. Krymgol'ts has identified as Megateuthis elliptica Mill. and M. longa Volt., both of which are characteristic of Bajocian deposits.

Farther west, as mentioned above, the crinoidal limestones are replaced by quartz-felspar sandstones with biotite, distinguished in the IV productive stratum in the Barakayev area.

In the cores of deep exploratory drill holes in the Barakayev area, approximately 40 - 50 m below the biotite sandstones of the IV stratum, was found Leioceras opalinum Rein., and somewhat above this level Parkinsonia aff. parkinsoni Sow., Garantia sp. and other Upper Bajocian fauna. The ages of the series underlying and overlying the biotite sandstones have also been confirmed by the discovery of an extensive foraminifer faunal assemblage, among which, in the underlying deposits, have been found Lenticulina rotulata (Lam. L. varians (Born.), L. matutina (Orb.), L. cordiformis (Terq.) and Globulina oolitica (Terq.), indicating that these deposits are of Aalenian-Toarcian age. Above the sandstone stratum the following foraminifera were found: Lenticulina stellaris (Terq.), L. semiinvoluta (Terq.), L. mamillaris (Terq.), Garantella floscula Kapt. (identifications by Z. A. Antonova).

A completely similar picture is revealed in the Besleneyevsko-Shchedokskiy district. Here the sandstones quite clearly separate the deposits of the Lower Jurassic from the argillites of the Bajocian stage. Both are here fully characterized by their foraminifer fauna.

In the vicinity of the Belaya River the deposits of the Bajocian stage were traced by the present writer westward from the village of Khamyshki, where along the upper reaches of a tributary of the River Kurdzhips (the Cholondarskiy brook) and along the upper reaches of the River Mezmay, black argillites lie unconformably upon deposits of Toarcian-Aalenian age. The biotite sandstone stratum was not encountered in exposures here, but the argillites contained foraminifera typical of Bajocian deposits: Lenticulina semiinvoluta (Terq.), L. costifera (Terq.), Vaginulina flabelloides (Terq.), Globulina oolitica (Terq.), Dentalina soluta Rauss and others.

In the Pshekha River basin, the Upper Aalenian and Bajocian deposits were studied by this writer in natural outcrops along the river and some of its tributaries. Here deposits of the Bajocian [1] lie unconformably upon argillites of the Upper Aalenian; the former contain a basal conglomerate with fragments of argillites and siltstones of Upper Aalenian age. Above the basal strata, the deposits of the Bajocian stage are represented by dark gray and black argillites with infrequent interbedded marl-siderite concretions. The age of the argillite was established by occurrences in it of the ammonites Dorsetensia tecta Buckm. and Holcobellus cf. blainvillei V. and, in the foraminifer assemblage, Lenticulina articulata (Terq.), L. sphaerica K. et Z.. L. pseudocrassa Mjatl., L. semiinvoluta (Terq.), L. praerussiensis Mjatl., Darbyella sp., Polymorphina sp. and others typical of the Bajocian stage. The underlying sediments, of Upper Aalenian age, are characterized by the ammonites Hammatoceras cf. auerbachensis Dorn., Ludwigia obtusiformis Buckm., Ludwigia patula Buckm., Reiusella cf. linneata Buckm. and others [3].

Such are the principal data at the present writer's disposal. These indicate quite reliably that in all the sections studied, the deposits of Bajocian age lie transgressively upon the underlying deposits. Moreover one may note the somewhat greater degree of erosion of the crests of anticlinal structures, which, it is believed, were formed in the pre-Callovian phase of folding. The data obtained by this writer allow him to assert that the initial stages of the Adygey phase began to be manifested as early as the boundary between the Aalenian and the Bajocian. In places, for instance along the Pshekha and Belaya Rivers, small angular and azimuthal unconformities have been observed, testifying to the low intensity of the folding movements occurring during that time.

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BRIEF COMMUNICATIONS

PETROGRAPHIC CHARACTERISTICS OF THE COALS OF THE MILLEROVO GEOLOGICAL DISTRICT OF THE DONETS BASIN

by V. N. Barbashinova

Prospecting work in the northeastern part of the Great Donets Basin among the coal deposits of the Millerovo district has resulted in the discovery of coals closely resembling brown coals.

The coal deposits exposed in this area belong to a suite of the Middle Carboniferous and are represented by alternating beds of argillites, siltstones, sandstones and limestones, with a total thickness of about 1300 m. These Carboniferous rocks are characterized by a slight degree of metamorphism in comparison to the coal-bearing rocks in the more southern districts, along the margin of the Donets Basin. Cretaceous and Tertiary deposits lie unconformably upon the eroded surface of the coal-bearing rocks.

Structurally and tectonically the district is part of the northern flank of the great Gluboka synclinal fold whose flanks dip very gently: from 0.5° north to 2° south of Millerovo.

The series of coal-bearing deposits, according to the presently available data, includes more than 15 coal beds, of which more detailed prospecting studies have been made and thicker coal seams have been found in suite C_2^5 and seams k_5, k_5^8, k_5^H. The latter in the majority of cases have a complex structure, and their thickness varies on the average from 0.2 - 1.5 m. The coal beds occur primarily among sandy clay rocks. The majority of coal seams are characterized by the presence of remains of roots in the soil, indicating their autochthonous origin.

The occurrence, among the coal deposits of the northeastern part of the Donets Basin, of coals that are brown or close to brown is an interesting phenomenon in the geology of the Donets Basin, and shows the necessity for a detailed study of the original plant material that served as the source of the coal matter, and of the conditions of the latter's accumulation.

The present writer has made a petrographic study of the coal seams from drill holes through the suites: $C_2^3(h_8,\ h_{11})$, $C_2^4(i_1^1)$, $C_2^5(k_5,$ k_5^B, k_5^H, $k_6)$ and $C_2^6(l_2)$.

As is known, the classification of the coals of the Donets Basin is based on the structure of the gelified substance [1] and its type according to its reducing properties [2]. On the basis of the classification suggested by V. S. Yablokov and L. I. Bogolyubova for the Middle Carboniferous coals of the Southwestern Donbass, this writer has distinguished the following petrographic types among the coals of the Millerovo district: I - coals with xylovitrain gelified substance and II - coals with homogeneous gelified substance (Table 1).

Macroscopically these are dull, semi-dull or banded semi-glistening coals, in which the general dull background is interrupted by bands and lenses of brightly glistening vitrain.

CLARAIN AND CLARODURAIN COALS

a) Banded semi-glistening mixed clarodurains. Microscopically this coal consists of interlayered bands of vitrain with bands of clarodurain. The predominant color of the gelified substance is red, in places with a yellowish tinge. Semi-translucent and opaque groundmass is observed only in certain areas. The cellular wood tissue is variously represented. Gelified and fusainized varieties are distinguished according to the nature of their alteration.

The gelified tissues are seen to contain vitrain, xylovitrain and rarely xylain. The vitrains have various structural and optical properties. A considerable part of them is characterized by the lack of any visible structure in transmitted light with one nicol. More rarely one sees vitrains with cellular structures; the latter can be seen from the difference in color between the cell walls and the cell vacuoles. Frequently the vitrain lenses are marked by a ring of cuticle. With crossed nicols one may quite clearly see xylovitrains, of which the most characteristic is a nodular xylovitrain ringed

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[1] K petrograficheskoy kharakteristike ugley Millerovskogo geologicheskogo rayona Donbassa.

TABLE 1

Petrographic Types of Coal in the Millerovskiy District

Type and variety of coal	Type of matter (in %)					
	gelified			fusain-ized	cuti-nized	resin-ous bodies
	xylo-vitrain	homo-geneous	total content			
I						
Clarain coals with xylo-vitrain gelified matter						
a) banded semi-glistening mixed clarodurains	40	15	55	20	18	7
b) fine-banded or streaked xylovitrain-vitrain duro-clarains	60	10	70	10	15	5
c) fine-banded or streaked xylovitrain-vitrain clarains	65	20	85	4	3	8
II						
Durain coals with homo-geneous gelified matter						
a) homogeneous semi-dull resinous durains	5	20	25	25	10	40

with cuticle. In small patches there are red and brown xylains with a characteristic rare-banded structure under crossed nicols. Along with the red gelified tissues, one frequently sees orange tissues of various sizes, shapes and structures.

Fusainized stem tissues are rarely encountered. They are represented by inclusions ranging in nature from typical fusain to vitrain-fusain. The bands of clarodurain contain large amounts of fusainized attritus.

Cutinized elements are represented mainly by microspores. Macrospores are usually few in number. In some layers the cuticle is quite prominent; usually it takes the form of bands of various thickness. In some thin sections one may observe accumulations of thin-walled cuticle.

Resinous bodies are encountered either as inclusions of various forms or as tiny drops of resin, filling the cells of the plant tissue.

Mixed clarodurain is most characteristic of h_8.

b, c). Fine-banded or streaked xylovitrain-vitrain duroclarain.

Under the microscope this coal is seen to consist of interlayered bands of vitrain with bands of clarain and duroclarain. Under high manification the gelified substance shows a nodular structure. The color of the groundmass and of the vitrain is red. In the duroclarain bands the formed elements are represented mainly by the lenses of xylovitrain and vitrain. The opaque groundmass is observed as rare inclusions. Fusainized tissues are not characteristic of this coal.

The cutinized elements are represented chiefly by shells of microspores, rare macrospores and fragments of cuticle. In some places one may observe accumulations of resinous bodies.

Some isolated parts of the coal are mineralized by fine-grained calcite. Pyrite in places encrusts the cuticle and gelified tissue.

This petrographic variety composes separate layers in almost all the investigated coal seams, but is most characteristic of beds l_2 and h_{11}.

DURAIN COALS WITH HOMOGENEOUS

a) Semi-dull, sometimes homogeneous resinous durain. The distinguishing feature of this coal is the quite uniform composition of the formed elements, represented primarily

by resinous bodies, which frequently form accumulations. The resinous bodies are of various shapes. Often they are rounded or ellipsoidal, sometimes linear elongated or even angular. The structure of the groundmass in this type of coal is homogeneous, and in places appears to be banded.

The fusainized substance is represented mainly by an opaque mass. Fragments of tissue in the form of xylofusain and fusain are rarely observed in this type. The coal contains small quantities of gelified tissue and cutinized elements.

The mineral admixtures are represented by clay minerals and quartz, which is encountered as more or less rounded grains of various sizes.

The resinous durain is most characteristic of beds i_1^1 and k_5, where it composes either the entire bed or else individual layers in it.

It should be noted that these coals gradually grade into each other. For this reason the frequently encountered transitional coals are only tentatively assigned to one of the three varieties distinguished. A distinctive feature of the microstructure of all three varieties is the constant presence of some quantity of resinous bodies.

This petrographic study of the Millerovo coals has shown that the source material for these coals must have been: 1) the stem parts of plants, frequently with their cell structure preserved, 2) cutinized elements represented by microspores and macrospores and 3) resinous bodies. Thus the original material of the Millerovo coals was higher spore vegetation.

The majority of the coals studied in the Millerovo district are characterized by the following: 1) a high development of xylovitrain-vitrain gelified substance in some types and homogenous gelified substance in others; 2) a fine-banded or micro-banded structure; 3) red color of the gelified substance; 4) the presence of orange stem tissue, lighter in color than the remaining mass of the coal; 5) a considerable content in the durain bands of a fine attritus of fusainized material.

The clarain coals with xylovitrain-vitrain gelified substance in the deposit may apparently be regarded as "more reduced", according to the classification of V. V. Vidavskiy [2].

Table 2

Petrographic coal type	W^a	Air-dry A	Air-dry S	V^{amf}	C^{amf}	H^{amf}	Specific weight	Heat value, Q	Humic acids, %	Nature of coke bead
Durain coals with homogeneous gelified matter	6,6	14,9	1,9	47,9	71,79	5,36	1,49	$\frac{5580^{a}}{7070^{amf}}$	No data	Powder
Clarain and claro-durain coals with xylovitrain gelified matter	5,2	27,5	3,3	45,0	67,04	5,01	1,66	$\frac{4620^{a}}{6720^{amf}}$	3,2	"
Same	11,6	6,8	3,5	46,0	72,76	5,27	No data	$\frac{6000^{a}}{7280^{amf}}$	2,7	Weakly cohesive
Durain coals with homogeneous gelified matter	4,5	19,6	3,1	47,2	No data	No data	1,15	No data	No data	Powder
Clarain and claro-durain coals with xylovitrain gelified matter	6,5	8,8	4,7	45,6	71,03	5,16	1,47	$\frac{6080^{a}}{7130^{amf}}$	2,5	"
Same	3,7	23,5	4,6	44,6	71,32	5,43	No data	No data	3,48	"

The coals studied for this paper have the following chemical engineering properties.

Technical analysis has shown the organic mass of the coals to have the following composition (Table 2, in %): moisture (W^a) 3.7 - 11.6; ash (A^{ad}) 6.8 - 27.5; sulfur (S^{ad}) 1.9 - 4.7; volatile matter (V^{amf}) 44.6 - 47.9. The calorific value (Q) is 6720 - 7280 kilocalories per kilogram. (a = as mined; ad = air-dry; amf = ash and moisture free).

The coke bead is usually powdery or slightly cohesive. Free humic acids were found, whose content varied from 2.5 to 3.48%.

Analysis for elements in the ash and moisture free mass showed the following results (in %): carbon (C) 67.04 - 72.76; hydrogen (H) 5.01 - 5.43.

The coals are characterized by a brown streak on the porcelain streak-plate and the appearance of numerous desiccation cracks and slight anisotropy of the gelified microcomponents.

These properties indicate that the coals of the Millerovo district may be regarded as high-gelified brown coals standing at the boundary between these and long-flame coal.

Thus these data indicate a new brand of DB coal for this part of the Donets Basin and confirm the gradual change in the degree of metamorphism of the coals in the same Middle Carboniferous suite, from brown (in the north) to hard coal at the northern margin of the Donets Basin.

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LAWS GOVERNING THE DISTRIBUTION OF THE COAL DEPOSITS IN THE SOUTHWESTERN PART OF THE MOSCOW COAL BASIN

by K. K. Rozhdestvenskaya

The southwestern sector of the southern flank of the Moscow Basin is a new coal-bearing area, within which extensive prospecting is being done for brown coals.

Because of the newly discovered coal-bearing prospects of this territory, the problem of the laws governing the distribution of the coal deposits has acquired great significance, since on its solution depends the proper carrying out and the success of the prospecting work.

Papers by a number of investigators of the Moscow Basin contained information on the stratigraphy and genesis of the Lower Coal Measures deposits and their facies changes, present structural tectonic analyses of the territory, analyze the processes of sedimentation and, in connection therewith, deal with the laws governing the accumulation of coal. The majority of investigators believe that the decisive factor in the distribution of the coal deposits is the structure and morphology of the relief of the pre-coal basement, associating intensive coal accumulation with the slopes of local uplifts.[2]

On the other hand, the data of prospecting work done in recent years by the Geological Administration of the Central Districts leads to the conclusion that the finding of industrial coal deposits occurring on the slopes of the uplifts does not exhaust the problem. Within the southwestern part of the Moscow Basin, along with coal-bearing districts in which industrial deposits occur on the slopes of uplifts of the limestone basement (the Kaluga, Kozel'sk, Sukhinichi, Baryatino, Dorogobuzh districts), there are also districts in which the deposits are associated with depressions in the structural surface of the basement (the Vskhodsko-Spas-Demensk and Semlevo districts). Hence arises a question which is of both theoretical and practical interest: what were the conditions under which deposits of industrial importance were formed in the areas of depression and subsidence? Is the localization of such deposits in them a matter of chance, or are the latter also associated with definite elements of the relief?

From a comparison of the facies and the lithologic composition of the deposits in the coal-containing (Stalinogorsk) stratum and their thicknesses with the structural-morphological elements of the pre-coal basement, one may with greater or lesser reliability reconstruct the relief of the locality in the period in which these sediments were accumulated, and draw certain conclusions regarding the distribution of the coal deposits in the southwestern part of the Moscow Basin.

From the standpoint of tectonics, this territory is a part of the so-called Bryansk-Orslavl trough, that connects the Moscow Basin with the Dnepr-Donets basin, and of its northwestern and southeastern slopes (Figure 1). The lowest points of the surface of this basin (below 20 m of absolute elevation) are in the northeastern part, where it is exposed in the Moscow syneclise.

In the center of the basin and across it there is a chain of depressions of smaller order, forming a single trough or channel cutting across the basin from southeast to northwest.

The slopes of the basin are located at elevations from 100 to 200 m and are complicated by differentiated uplifts; the axial part of the basin also contains individual uplifts whose trend, in common with the basin, is from southwest to northeast.

With these structural elements are associated the definite types of deposits of the coal-bearing (Stalinogorsk) stratum.

In the center of this territory the intersecting chain of basins is filled with sands composing the lower part of the section of the coal-bearing

[1] K voprosu o zakonomernostyakh raspredleniya ugol'nykh zalezhey v yugo-zapadnoy chasti Podmoskovnogo basseyna.

[2] See K. Yu. Volkov, A Forecast of the Coal Resources of the Southwestern Flank of the Moscow Basin. Tr. Geol.-Issled. Byuro Glavugol'razvedki, vyp. 1, 1947.

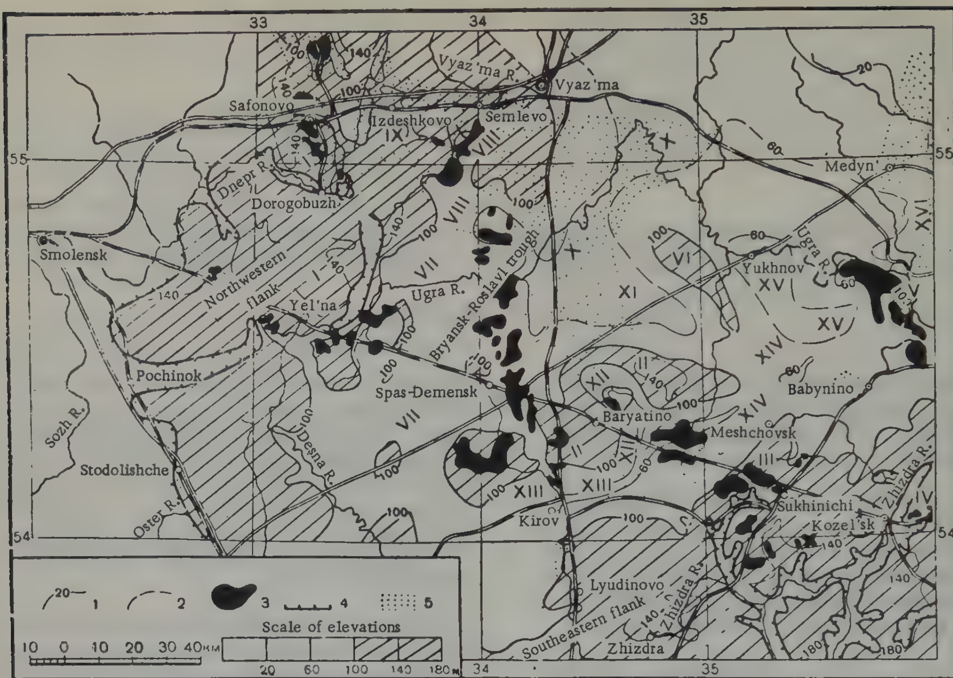

FIGURE 1. Hypsometric structure-contour sketch map of the top of the limestone basement (in the southwestern part of the Moscow brown-coal basin):

1 -- structure-contour lines at the top of the limestone basement; 2 -- same, conjectural; 3 -- occurrences of coal, as discovered by detailed, preliminary and prospecting surveys; 4 -- areas of recent erosional exposure of the top of the basement; 5 -- areas of distribution of the lower sandstone formation in the Stalinogorsk stratum; I -- Safonovo-Yel'na uplift; II -- Baryatino uplift; III -- Sukhinichi uplift; IV -- Kozel'sk uplift; V -- Kaluga uplift; VI -- Dobrynskoye uplift; VII -- Ugra depression; VIII -- Semlevo depression; IX -- Izdeshkovo depression; X -- Vyaz'ma depression; XI -- Dubrovka depression; XII -- Nepolodevskaya depression; XIII -- Kirov depression; XIV -- Babynino depression; XV -- Yukhnov depression; XVI -- Kamel'ga depression.

deposits. This sand series has the nature of channel deposits: the sands are usually fine-grained and small-grained, in places uneven-grained and large-grained with pebbles, gravel and rubble; here and there one observes cross-bedding. The sands begin with two "channels" on the southeastern slopes of the basin and extend thence northward (Figure 1). Its two branches surround the southern part of the Baryatino uplift, occupying the depressions that surround it (the Kirov and Nepolodevskaya), and thence moves northward and northwestward along the depressions in the surface of the basement (the Dubrova basin, and the Vyazma, Semlevo, Izdeshkovo depressions). The width of the belt of sands increases as one moves northward, reaching its maximum in the northwest, where the sands move up the slopes of the Bryansk-Roslavl basin to absolute elevations of 120 to 140 m or more. The thickness of the sand series is considerable, some 20 to 30 m on the average, and in the deepest parts of the depression reaches 50 m or more.

The upper part of the section through the coal-bearing series (the Stalinogorsk stratum) is composed of lacustrine-swamp carbonaceous clay deposits, which occur universally throughout this territory. The sands underlying them, with the exception of the above-described belt, are of small thickness. The total thickness of the Stalinogorsk stratum on the average is 5 to 25 m, but reaches 40 to 60 m in the sandy region, and more than 80 m in particular places.

Two types of carbonaceous-clay deposits have been distinguished—plastic and oily—as well as dry and semi-dry clays with coal seams of working thickness and sandy, sometimes highly sandy, clays with thin, high-ash coals. The former are associated principally with the uplifts on the slopes of the Bryansk-Roslavl basin, where the deposits of industrial significance are located, whereas the sandy clays with discontinuous thin coal seams are located in the areas of depression.

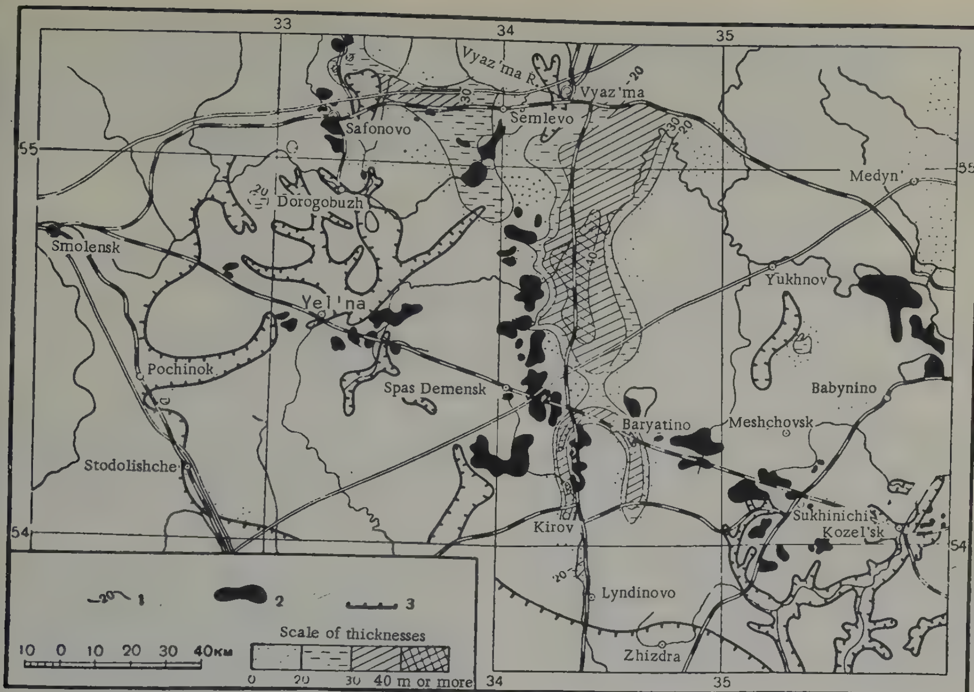

FIGURE 2. Isopach sketch map of the lower sandstone formation in the Stalinogorsk stratum (southwestern part of the Moscow brown-coal basin):

1 -- isopachs of the lower sandstone formation in the Stalinogorsk stratum; 2 -- deposits discovered by detailed, preliminary and prospecting surveys; 3 -- areas of complete erosion of the Stalinogorsk stratum.

An exception here is a zone extending along the sandy belt on the west: in this zone the coal-bearing deposits are also represented by plastic, oily and dry and semi-dry clays, with coal-forming deposits of industrial importance. Such are the Spas-Demensk, Vskhodsk, Poldnevsk and Semlevo deposits; these form a chain along the western margin of the sandy channel-deposits.

The relationship between the distribution of deposits in the area of the basin and the direction of the sand belt is apparently explained by the following geographical circumstances in the period of their accumulation. In pre-coal times this territory was a differentiated surface with an extensive lowland in the center, intersected by a deep trench, and with highlands along its western and southeastern margins (and to some extend in the center). In Early Viséan times streams of water rushed down into the low areas from the high southeastern margin, using the intersecting trench as a convenient path and filling it with sandy deposits. This was followed by the formation of a valley with a floodplain and terraces. In all probability the peculiar nature of its sediments, was a terrace of this ancient valley, where special conditions led to the intensive accumulation of coal, and thereafter to the formation of industrial deposits. While the stream of water-currents was cutting its valley, accumulation of lacustrine-swamp clay-sand deposits was taking place throughout all the surrounding area; on the gentle slopes of the highlands were formed plastic and dry clays with thick coal seams, and over the extensive plain areas sandy clays with thin, discontinuous coal interbeds. The existence of such considerable amounts of sandy material over most of the plain was apparently due to the transportation of sand resulting from the leveling of the surrounding highlands.

Thus the areas of intensive coal accumulation were supposedly the gentle slopes of highlands in the pre-coal relief and in depressions — the terraces of ancient river valleys. In the present relief of the basement surface, the ancient terraces are poorly reflected or nonexistent. The positions and directions of the ancient valleys (and, consequently, terraces) is fixed by the location of the thick series of sands that fill the ancient channels.

From all this it follows that the discovery of the structural elements of the pre-coal relief in the areas of depressions and the direction of

prospecting work is determined by the data of facies and lithologic analysis, which make possible a reconstruction of the paleogeography of the period in which the coal was accumulated. The results of such facies-lithologic analysis have supplemented existing concepts regarding the laws governing the distribution of industrial deposits in the southwestern part of the Moscow Basin, and the hypothesis that the latter are associated, within depressions, with the terraces of ancient river valleys. This hypothesis is only a partial answer to the question that has been posed.

BRIEF COMMUNICATIONS

PECULIAR CALCITE CRYSTALS FROM THE VERKHNIY RUDNIK DEPOSIT, TETYUKHE[1]

by N. N. Mozgova and D. I. Pavlov

In the middle strata of the Verkhniy Rudnik deposit, in a mineralized cavity within a highly carbonatized hedenbergite skarn, have been found some interesting calcite crystals, whose c axis is up to 3 cm long (Figure 1).

The mineralized cavity, $0.7 \times 0.3 \times 0.7$ m^3 in volume, was located in a zone of intensive saturation with ground waters that were apparently very rich in calcium. This supposition is supported by the formation of tiny stalactites of calcite on pieces of an old wire hanging from the ceiling of the mine stope. The lower part of the cavity was observed to contain a wet mass of the products of leaching of the hedenbergite, represented mainly by a loose aggregate of acicular calcite. The needles composing this aggregate are not intergrown, but form a mechanical mixture of variously orientated units, thus naturally creating a large number of interstices between them. The needles themselves are brittle, opaque and average no more than 2 to 3 cm in length, their diameters being no more than several millimeters. This loose acicular mass had to be removed from the cavity by handfuls. When examined more carefully, it was found to contain individual crystals of a peculiar development. Unfortunately their disposition within the acicular mass directly in the cavity could not be observed.

Certain of these crystals are characterized by prismatic habit and are terminated on both ends by scalenohedra (Figure 1a), while others have a very peculiar club-shaped appearance: one end of the crystal has an elongated, sometimes very thin and almost needle-like stem, and the other end of the crystals forms a thicker head (Figure 1b).

Goniometric study of the prismatic crystals (Figure 2a) has shown a predominant development of the prism faces m $[10\bar{1}0]$ and to a lesser degree of *a* $[11\bar{2}0]$. The heads are represented by the scalenohedra K: $[21\bar{3}1]$, and between the K and a faces, in the form of very small truncations, are the rhombohedral faces m $(40\bar{4}1)$. The K and a faces bear strong identical striations parallel to their common edge (Figure 2a), and apparently produced by the alternation of faces of the prism with faces of several more acute scalenohedra, among which the scalenohedron N — $(53\bar{8}2)$ has been established. The faces m $(40\bar{4}1)$ are also striated parallel to their edge with the prism m $(10\bar{1}0)$; the faces of the latter show no striations, but have very characteristic ellipsoidal vicinal growths.

Measurement of the club-shaped crystals (Figure 2b) has shown that the "stem" corresponds only to the above-described prismatic crystals and is formed mainly by the faces a $(11\bar{2}0)$ and m $(10\bar{1}0)$, while in the thicker part of the crystals the a $(11\bar{2}0)$ faces are lacking, the m $(10\bar{1}0)$ and m $(40\bar{4}1)$ faces are very small, whereas the dominating development is that of the scalenohedra K: $[21\bar{3}1]$, and the negative rhombohedron δ $[\bar{0}112]$ is also well developed. In addition, small faces of the basal rhombohedron p $[10\bar{1}1]$ are observed as truncations of the edges of this rhombohedron and scalenohedron.

Both types of crystals have c axes of the same length, but in the club-shaped crystals the "stem" has a much smaller size as compared to both its head, and the prismatic crystals, although it has the same crystallographic form as the latter (see Figures 1 and 2). It is interesting that in the prismatic crystals (as may be seen in Figure 3 as well) there are inclusions of opaque acicular calcite, which forms the loose mass that contains these crystals. In the transparent heads of the club-shaped calcite, inclusions of this type are not observed.

These facts suggest that both the prismatic and the club-shaped calcite are simultaneous formations, and it is not impossible that their origin is due to recent saturation of the mineral cavity with solutions. The prismatic crystals evidently grew in crowded conditions directly in the loose mass of acicular calcite, encompassing individual needles as inclusions. The

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[1]Svoyeobraznyye kristally kal'tsita iz mestorozhdeniya Verkhniy Rudnik, Tetyukhe.

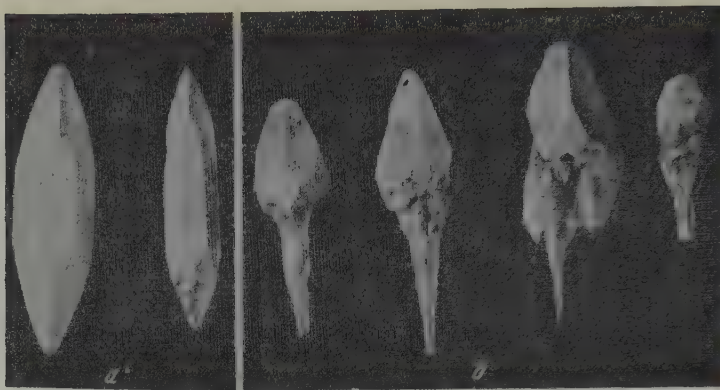

FIGURE 1. Two types of calcite crystals from a single cavity in skarn: a - prismatic, b - club-shaped. Magnification x 2 (specimens dusted with MgO powder).

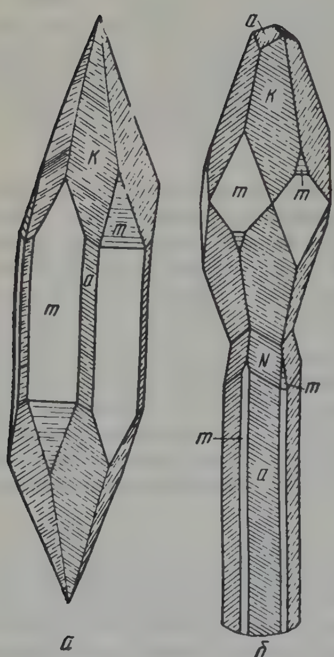

FIGURE 2. Development of crystallographic forms on prismatic (a) and club-shaped (b) calcite.

FIGURE 3. Head of club-shaped calcite without inclusions (a), and prismatic calcite with inclusions of acicular carbonate (b). Magnification x 2.5.

stems of the club-shaped crystals probably grew under analogous conditions, whereas the heads of these crystals, which contain no inclusions of the surrounding calcite, in all probability developed in the cavities within the loose acicular aggregate as free growths. The greater magnitude of the heads of the club-shaped crystals as compared to their stems may in this case be explained by the standing of the solution in the gaps, as well as by the smaller pressure here than in the surrounding medium.

REVIEWS AND DISCUSSIONS

ON THE TYPES OF CARBONATITE DEPOSITS AND THEIR ASSOCIATION WITH MASSIFS OF ULTRABASIC ALKALINE ROCKS[1, 2]

by

L. S. Yegorov

An article with the above title by L. S. Borodin was published in the "Bulletin of the Academy of Sciences of the U. S. S. R., Geologic Series", No. 5, 1957. Later the same publication printed some remarks by N. A. Volotovskaya and A. A. Kukharenko [2] with a number of serious objections to the basic petrogenic conceptions set forth in the above-mentioned article. The authors of these critical remarks, in correcting what they considered to be the erroneous conclusions of L. S. Borodin, used materials on the pyroxenite-iolite intrusives of the Kola Peninsula, stating that the applicability of the disputed hypothesis to the Siberian massifs of ultrabasic and alkaline rocks must be tested by geologists directly concerned with studying the latter.

Before taking up this idea, a few words summarizing the essence of L. S. Borodin's conception are in order. This investigator, in considering the geologic occurrence of carbonatites and the general structure of complex massifs of alkaline and ultrabasic rocks (relying mainly on sources in the literature and partly on his own observations) came to the following main conclusions: 1) the only igneous rocks of these massifs are hyperbasites, in the first place among which are pyroxenites; 2) the alkaline parts of the massifs (iolite-melteigite) are of metasomatic formation, through nephelinization of the pyroxenites; 3) nephelinization of the pyroxenites ultimately leads to processes of iron-magnesium-calcium metasomatism, manifested in the formation of apatite, perovskite, phlogopite, etc., and to the formation of melilitic rocks and carbonatites.

As one of the geologists who have for a number of recent years been making detailed investigations of the large intrusives of alkaline and ultrabasic rocks in the northern part of the Siberian platform — the Gula, Odikha, Kugdu, Magan intrusives and others — the author of the present article cannot remain indifferent either to certain undoubtedly erroneous concepts of L. S. Borodin or to the essentially negative attitude adopted in regard to the hypothesis of "nephelinization" by N. A. Volotovskaya and A. A. Kukharenko.

The recent investigations of Yu. M. Sheynmann, G. G. Moore, Ye. L. Butakova, T. L. Gol'dburt, K. M. Shikhorina, L. S. Yegorova and others of the alkaline-ultrabasic massifs of the Maymecha-Kotuy region have established the complex, multiphase history of its igneous development. In this history the injection of the iolite-melteigite intrusions is quite an important episode and is far from being the last. The igneous nature of the main mass of iolite-melteigites is indicated by their typical hypidiomorphic structure, which becomes porphyritic in the endocontact zones (in the case of contacts with sedimentary rocks). The porphyritic structure quite clearly reflects the cooling surfaces of the contact, and is reflected in the presence within the rock of scattered euhedral grains of nepheline and lesser amounts of pyroxene, around which the grains of the fine-grained groundmass flow. There is little point in citing the many other indications of the intrusive origin of a considerable part of the iolite-melteigites of the Maymecha-Kotuy petrographic province, since they would merely repeat the similar and very convincing arguments presented by N. A. Voltovskaya and A. A. Kukharenko in regard to the identical rocks of the Kola Peninsula.

We shall merely stress that in the northern part of the Siberian platform the inapplicability of L. S. Borodin's conception of the panmetasomatic genesis of the nepheline rocks is

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[1] O tipakh karbonatitovykh mestorozhdeniy i ikh svyazi s massivami ul'traosnovnykh — shchelochnykh porod.

[2] In connection with the article by L. S. Borodin and its criticism by N. A. Volotovskaya and A. A. Kukharenko.

especially clear, in view of: 1) the widespread development here of extrusive nepheline-containing rocks — melanocratic nepheline basalts, nephelinites and others; 2) the existence in many complex intrusions of this region of porphyritic and trachitoid rocks whose composition is intermediate between peridotite-pyroxenites and iolite-melteigites. The latter (olivine jacupirangite-melteigites, melanocratic nepheline dolerites and others) were intruded after the peridotite-pyroxenites but before the iolite-melteigites, contain schlieren of peridotites, malinites and melilitic rocks, and serve as an excellent criterion for judging the course of differentiation of original magma.

The zone of extreme hardening of the olivine-containing jacupirangite-melteigites, as shown by observations of L. S. Yegorov and N. P. Surina in the Changit intrusive, is composed of melanocratic nepheline basalts and limburgites, which is strong testimony in favor of Ye. L. Butakova's conclusion [1] that the entire varied gamut of rocks of the alkaline-ultrabasic intrusive complex arose during the process of differentiation in the depths of the alkaline basaltoid magma.

It must be said that L. S. Borodin's denial of the possibility of an iolite-melteigite magma separating from a peridotite or basalt magma, which he argues in his article on the basis of abstract considerations, does not logically follow. After setting forth the essence of his views on the role of nephelinization, L. S. Borodin, in looking for a source of the "nephelinizing" solutions, is compelled in spite of himself to assume that this most likely must have been the alkaline magma. But the question arises: is this assumption sufficient to discredit completely the exclusive role of metasomatism in the formation of the iolite-melteigite rocks?

Along with the definitely igneous iolite-melteigites, the massifs of the Maymecha-Kotuy region do actually contain metasomatic rocks of nepheline-pyroxene composition, as first noted by Ye. L. Butakova [1].

Observations by the author of this article in the Kugda, Magan and Odikhincha intrusives, by Ye. L. Butakova in the Gula intrusive and in Dalbykha, by A. I. Ivanov and V. P. Safronov at Nemakita and by V. F. Motychko at Odikhincha have shown that the metasomatic nepheline-pyroxene rocks are usually distinguished by their fine-grained granoblastic or porphyroblastic structure, and are relative widespread, associated chiefly with the contact zone between the iolite-melteigites and the pyroxenites.

In view of the information accumulated up to the present time, the fine-grained nepheline-pyroxene rocks of granoblastic and porphyroblastic structure cannot be considered as anything but the products of nephelinization of the pyroxenites, and in a number of cases of the olivinites and certain other rocks.

Various stages of nephelinization can be distinguished: impregnation of the pyroxenites by nepheline along fine fractures (in thin sections one may clearly see the corrosional development of xenoblastic grains of nepheline at the joints between the pyroxene units), recrystallization of the nephelinized pyroxenite into a fine-grained nepheline-pyroxene rock with a hornstone structure, and the growth of large poikiloblasts and porphyroblasts of nepheline. Ultimately the nephelinization results in formations that are quite sharply distinguished in texture and structure from the iolite-melteigites, while the contacts between both of these sometimes clearly preserve traces of the primary intrusive interrelationships between the pyroxenites and the iolite-melteigites.

In the light of what has been said above, one must acknowledge the correctness of L. S. Borodin's assertion regarding the great extent of nephelinization in the complex massifs of alkaline-ultrabasic rocks, but it is nevertheless impossible to agree with his statement that the nephelinization ended in the formation of the iolite-melteigites with a hypidiomorphic structure. From the genetic standpoint, the iolite-melteigites are not the result, but the cause of nephelinization of the pyroxenites (with which even L. S. Borodin to some extent agrees; see above). The nephelinization must be regarded as a case of metasomatism of the igneous stage, and must be compared in this sense with the well-studied process of phenitization of the enclosing rocks of granitoid composition, which it apparently closely resembles. It is worth noting that the first metasomatic "iolites", along with their igneous analogs, as described by C. A. Strauss and F. C. Truter [9] were considered by these geologists to be peculiar varieties of phenites.

This writer believes that L. S. Borodin is quite logical in concluding, with numerous proofs, that the nephelinization, as a result of its removal of 30 to 50% of the pyroxene from the pyroxenites, led to processes of iron-magnesium-calcium metasomatism. In the intrusives in the northern part of the Siberian platform, in the zones of nephelinization, there are actually intensive manifestations of phlogopitization of the pyroxene, diopsidization of the olivine, perovskitization and sphenization of the titanomagnetite and pyroxene, apatitization of all the minerals, etc; apparently, along with nephelinization, there is a formation of micas (from the pyroxenites) and accumulations of perovskite ores, as in the Odikhincha intrusive. In the Magan intrusive, according to the present writer's observations, the mafic components of the pyroxene that were removed in nephelinization migrated, together with the alkalis, into the surrounding quartzites, producing a broad zone of tweitosites (?). These almost

holomelanocratic varieties of phenite may be considered as the products of sodium metasomatism and basification of the quartzites.

Nevertheless a multitude of facts make it impossible to agree with L. S. Borodin's chief conclusion regarding the close genetic association between iron-magnesium-calcium metasomatism and the formation of the carbonatites, and also the origin of the melilitic rocks. In all the complex massifs of the northern margin of the Siberian platform the melilitic rocks (uncompaghrites and others) form morphologically distinct intrusive bodies of considerable size, which cut through the hyperbasites, but are in turn intersected and metamorphosed by the iolite-melteigites. The melilitic rocks of the Maimecha-Kotuy region, distinguished by the trachitoid areas in the porphyritic structure of the endocontact facies, in the opinion of all the geologists who have studied them, are for the most part of undoubted igneous origin. The problem of the carbonatites is more complicated. Ye. M. Epshteyn, for example, suggests that L. S. Borodin's conceptions are applicable in explaining the genesis of the carbonatites of the Gula intrusive.

On the other hand, a number of facts, above all the great sizes of the carbonatite bodies (up to 6 km^2), the isolated occurrence of certain stock-like carbonatite massifs in sedimentary carbonate rocks [4], the mostly clear and sharp contacts between the carbonatites and the surrounding rocks and the absence of any relicts of the latter (except for the occasionally encountered angular inclusions of xenolithic appearance) in the carbonatites, all strongly suggest that the carbonatite massifs are "injected bodies" and not "replacement bodies". They are apparently the same as, for example, the intrusives of pyroxenites or iolite-melteigites, but in contrast to these silicate formations the carbonates evidently underwent a much longer stage of pneumatolytic and hydrothermal development; during this process they were enriched in rare elements in particular, also undergoing a number of other mineral and structural alterations.

It has now been proved experimentally by O. F. Tattle [6] that a carbonatite melt can exist under hypabyssal conditions. In any case, even if one accepts a metasomatic formation for the carbonatites in the Maymecha-Kotuy region, their appearance cannot be connected in any way with the nephelinization of the pyroxenites, since these carbonatites intersect and metamorphose the alkaline syenites, which were, according to all indications, formed after the end of the nephelinization and the processes of magnesium-calcium metasomatism caused by it [3]. Moreover the Maymecha-Kotuy region shows no reliable physical connection whatever between the large carbonatite bodies and the intrusives in which the metasomatic nepheline-pyroxene rocks are exclusively developed. For example, in the Odikhincha massif (56 km^2), composed mainly of iolites and almost entirely of pyroxenites, the amount of carbonatites is negligible, whereas several stock-like and dike-like bodies of rare-metal carbonatites are grouped in the immediate vicinity of the Changit intrusive (0.4 km^2), which contains no nephelinized rocks.

In the light of the above observations, one is compelled to take strong exception to L. S. Borodin's supposition that the carbonatites include "only those carbonate rocks whose formation is associated with processes of metasomatic alteration of the ultrabasic rocks, and above all with processes of nephelinization", as well as his recommendation that "the presence of nepheline-pyroxene rocks of metasomatic genesis, associated with peridotites and pyroxenites" be considered the "most important criterion" in estimating the possibility of the occurrence of carbonatite deposits in the province of ultrabasic-alkaline rocks.

At the present time, when the investigation of carbonatites and the rare-metal mineralization associated with them has moved forward very little and much still remains to be done in the scarcely begun experimental study of carbonate melts, it would perhaps be more suitable to use the more general definition of carbonatites proposed by W. T. Pecora [8]. There is also still no serious basis for any categorical conclusions regarding the occurrence of carbonatite deposits in one province or another of alkaline and ultrabasic rocks, especially if one recalls that carbonatites are ingredients in all such provinces.

The intrusive complexes of ultrabasic-alkaline and carbonate rocks of different regions and geologic epochs resemble each other very closely [8]. This circumstance causes us to doubt the correctness of the assertion by N. A. Volotovskaya and A. A. Kukharenko [2] that in the intrusives of the Kola Peninsula, in contrast to their Siberian analogs, nephelinization of pyroxenites is either completely absent or plays a sharply subordinate role, the more so because the thorough and careful petrographic descriptions by B. M. Kupletskiy [7] provide objective evidence to the contrary.

N. A. Volotovskaya and A. A. Kukharenko quite properly reproach L. S. Borodin for exaggerating the role of metasomatism in the formation of the iolite-melteigites, but in defending their own position, they quite unjustly disregard the progressive tendency of the views they are criticizing. It must be acknowledged that L. S. Borodin's excessive generalizations have nevertheless given a definite forward push to investigations of the petrogenesis of alkaline-ultrabasic intrusive complexes.

More study is required of the complicated association between igneous and metasomatic processes in the formation of iolite-melteigite rocks, such as that made by V. A. Kononova in the Dakhunur intrusive [5].

It is to be hoped that new confirmations will appear of the existence of iron-magnesium-calcium metasomatism. Nevertheless in each concrete case the significance of the latter in the formation of carbonatites and rare-metal mineralization must be critically evaluated on the basis of the existing factual data. One must also constantly keep in mind the possibility of the igneous (intrusive) genesis of the greater part of the carbonatites, a conception which has by no means yet been overthrown and which has a serious basis in the geologic features of the carbonatite bodies in the northern part of the Siberian platform [3, 4] Africa and Scandinavia [8], as well as in the most recent physical-chemical investigations [6].

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REMARKS ON A. V. NETREB'S ARTICLE "ON THE AGE OF THE PYRITE MINERALIZATION IN THE NORTHWESTERN CAUCASUS"[1, 2]

by

N. S. Skripchenko

This article attempts to answer many questions regarding the genesis of the pyrite deposits in the Northwestern Caucasus and, to judge by his conclusions, its author believes that he has succeeded in carrying out his task. Nevertheless a look at the factual data presented in the article arouses doubts regarding the correctness of the conclusions. The chief conclusion is that the ore bodies were formed after regional metamorphism of the enclosing rocks. As a basis for this, the author cites the results of measurements of the direction of twinning planes of sphalerite relative to the banding in the ore. Using this method, A. V. Netreba indicates (p. 100) that the twins in the sphalerite are the result of mechanical deformation. Hence one might conclude that the massive development of twinning in the sphalerite of the banded ores indicates their dynamic metamorphism. This conclusion would also be drawn from the diagrams showing the orientation of the twin seams. In two of the four polished sections studied, the author observes the

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[1]Zamechaniya k stat'ye A. V. Netreba "O vozraste kolchedannogo orudeneniya na Severo-Zapadnom Kavkaze".

[2]"Bulletin of the Academy of Sciences of the USSR, Geologic Series", no. 3, 1959.

presence of "straight" and "diagonal" orientations in the twin seams (Figures 5b and 6b). But the patterns of the other two diagrams (Figures 5a and 6a) scarcely confirm his opinion of the absence of orientation in the corresponding thin sections. The pattern of Figure 6a quite closely resembles that of Figure 6b, which is considered to be straight orientation. Thus from a measurement of the orientation of sphalerite twins in the banded ores one may conclude only that the ores of the Beskess deposit have undergone dynamic metamorphism.

The comparison of the orientation of the sphalerite twins with the α_1 of albite sounds like a complete dissociation from the data of petrotectonics. Since the author has not used the precise method of determining the coordinates of the optical crystallographic elements of albite on the Fedorov universal stage, the graph might reflect not only the direction of α_1, but also that of β_1. Moreover the orientations of the twin seams, on the one hand, and of the γ_1 axes of plagioclase, on the other hand, are not comparable phenomena: in one case it is the twinning plane that is being compared, and in the other case an essentially random direction of the optical index.

It is appropriate to observe that the present writer has studied the orientations of the optical axes of the quartz-albite-chlorite schists of the Beskess deposit. According to the pattern of their orientation they turned out to be actually B-tectonites. But this cannot establish a measurement of α_1 of the albite, because the sizes of its grains are as a rule very small.

The other indications of the younger age of the ores relative to the main phase of tectogenesis are mentioned by the article only in passing, as if they were frequently observed.

On page 95, in characterizing the sulfur-pyrite ores, the author writes: "sometimes one encounters 'hanging' large blocks and fragments of the enclosing rocks — albitophyres and albite-chlorite schists, preserved from replacement"; and farther on: "sometimes the fragments are rotated, since the direction of the schistosity in them does not correspond to the direction of schistosity of the enclosing rocks". On page 97 this lack of correspondence is interpreted to mean that the schistosity is older than the mineralization.

In these few phrases the author solves not only the problem of the relative ages of the mineralization and the schistosity, but also the problems of the mechanism by which the ores were formed. If serious significance is to be attached to this, why does the article present no description—or at least only a sketch—of the inclusions?

In 1957 this writer made a detailed underground map of the Beskess deposit, in the preparation of which he encountered not one single such inclusion in the ore which might be considered to be rotated relative to the schistosity of the enclosing rocks. The ores sometimes contain thin interbeds of quartz-like rocks and chlorite schists. The schistosity in these is always in the same direction as the schistosity of the enclosing rocks. Since A. V. Netreb cites no accurately documented data testifying to the presence of inclusions of rocks with rotated schistosity in the ore, his conclusions regarding the relative age of the mineralization cannot be considered well founded.

The Beskess deposit, in this writer's view, contains no indications suggesting a decisive answer to this question. For example, this writer has observed slight pyritization in the tectonic zones intersecting the schistosity of the rock. Moreover there are quartz-barite veins which do not correspond in direction to the schistosity. These facts without contradiction testify to the ore mineralization having taken place after the dynamic metamorphism, but they are insufficient for concluding that the pyrite mineralization is younger in age than the dynamic metamorphism. On the other hand, some mention must be made of the presence within the Beskess deposit of ores with gneissic and cataclastic structures, which may be interpreted as indications of their dynamic metamorphism.

The existence of such contradictory evidence makes it impossible to answer the question of the genesis of the pyrite ores in the Northwestern Caucasus as categorically as does this article.

At the present time, in the Northern Caucasus, pyrite deposits in volcanogenic series that have not undergone dynamic metamorphism are being located and prospected; thus the possibility arises of solving the problem of the genesis of the pyrite deposits by comparing them with the features of deposits occurring in rocks metamorphosed to various degrees, as recommended by A. N. Zavaritskiy. The facts collected up to the present time, such as the widespread distribution of collomorphic ores in the deposits occurring among non-metamorphosed rocks (the Kizilkol' deposit) indicate rather that the ores of deposits of the Beskess type have undergone dynamic metamorphism.

LETTER TO THE EDITORS

The "Bulletin of the Academy of Sciences of the U. S. S. R., Geologic Series," No. 4, 1959, contains some critical remarks by V. G. Korel' on the subject of my article "Contact-reaction Phenomena between the Vein Granites and Skarn-ore Formations in the Sheregeshev Deposit of the Gornaya Shoriya", published in the "Bulletin"

(No. 5, 1956). These critical remarks by V. G. Korel' contain a number of subjective and unfounded assertions, as well as an incorrect citation of the text of my article.

My article, as will be seen from its title, was devoted to a detailed consideration of the peculiar contact-reaction phenomena between the skarn rocks and the vein granites that cut them. Here it was noted that these contact-reaction formations, along with other geologic facts, provide additional confirmation of the post-ore nature of the Sarlyk granites. In an article of his published earlier,[1] as well as in his critical remarks, V. G. Korel' proves the same thing. Thus V. G. Korel's objection is hard to understand.

In my article it is stressed that V. G. Korel's published work, especially devoted to contact metamorphism of the Sheregeshev deposit, fails to take account of many geologic facts (the presence of skarn and ore xenoliths in the granites, the extensive development of vein granites, etc.), although they are of essential significance for solving these problems.

Nevertheless the cited article by V. G. Korel' and his critical remarks contain contradictions and even completely incorrect statements. For example, according to V. G. Korel' pyrrhotite, biotite, isotropic varieties of garnet, and nonzonal magnetites are found only in the Sheregeshev deposit. This is not actually so. Pyrrhotite has long been known in the Shalym ores, and biotite in the Shalym and especially the Kochura ores. In exactly the same manner, optically isotropic and anisotropic varieties of garnets are observed in equal measure in all the iron-ore skarn deposits of the Kondomskaya group. Moreover optically anomalous garnets in the skarns of the Sheregeshev deposit were observed long ago by M. A. Kashkay (1934) and N. A. Batov (1935).

V. G. Korel' acknowledges the presence of granite apophyses in the skarn-ore formations and of their xenoliths in the granites. Nevertheless my completely suggestion that the skarn-ore formations were partially absorbed by the granites of the contact zone is quite unexpectedly proposed on the basis of unconvincing, mistaken and even, as it were, incorrectly oriented conceptions.

In this short letter there is no room for me to dwell on the igneous activity of the region and the genetic connection between the mineralization and the intrusives. These problems are considered in part in my article, printed in "Notes of the All-Union Mineralogical Society" (No. 2, 1958). It must be said, moreover, that V. G. Korel' in his critical remarks does not refer to this article, but in his list of references cites a paper on collomorphic formations of molybdenite and garnet which has no bearing on the discussion.

This is not the first time that V. G. Korel' has come out in print with his critical remarks which, unfortunately, reveal his subjective attitude to the facts.

V. A. Vakhrushev

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[1]Korel', V.G. Contact Metamorphism of the Sheregeshev Iron-ore Deposit in the Gornaya Shoriya. Izv. Tomsk. Politekhn. In-ta, t. 74, vyp. 1, 1953.

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CHRONICLE

The Department of Geological and Geographical Sciences of the Academy of Sciences of the U. S. S. R. has adopted a resolution to hold annual readings, on the anniversary of the birth of the outstanding Soviet scientist, Academician Aleksandr Yevgen'yevich Fersman, of papers devoted to the development of his ideas.

The first scientific reading in honor of A. Ye. Fersman was held on 23 November 1959, with a paper on "The Soviet Scale of Absolute Ages of Geologic Formations", by Academician D. I. Shcherbakov. He reported to the meeting on the figures for the absolute ages of geologic formations as obtained by a number of geological organizations in the U. S. S. R; these figures at the present time serve as a basis for the elaboration of a geologic scale of absolute time for the U. S. S. R.